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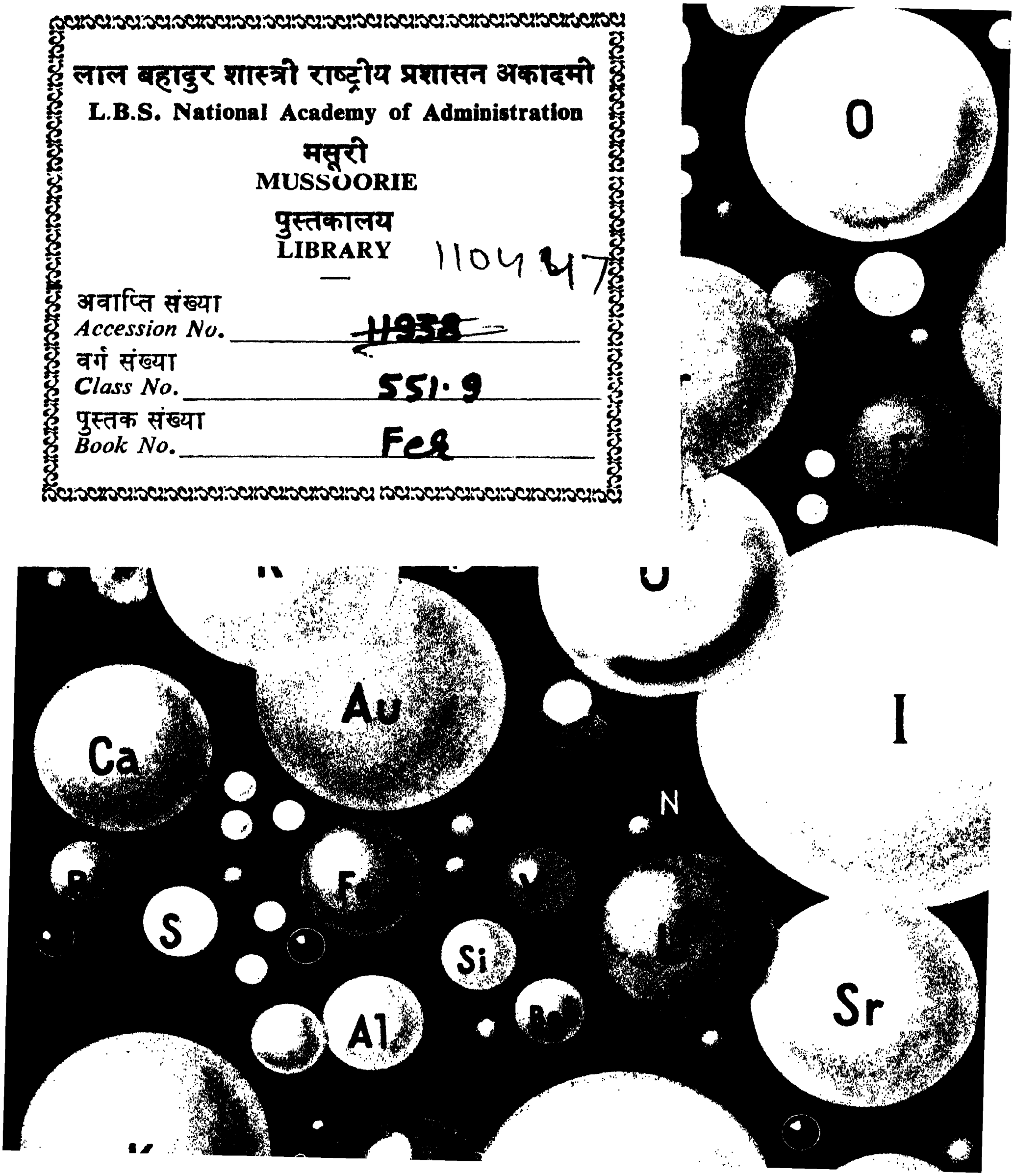

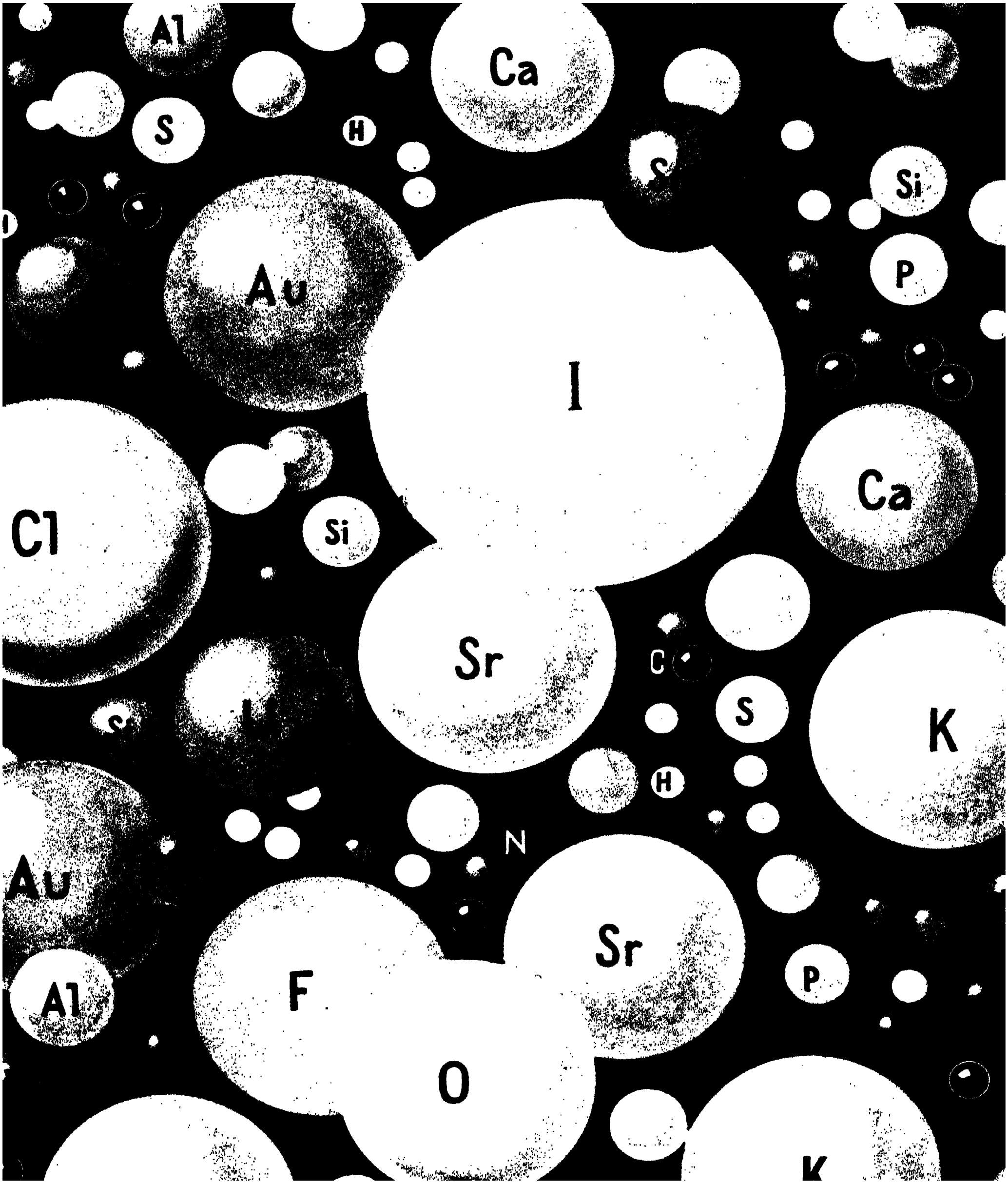
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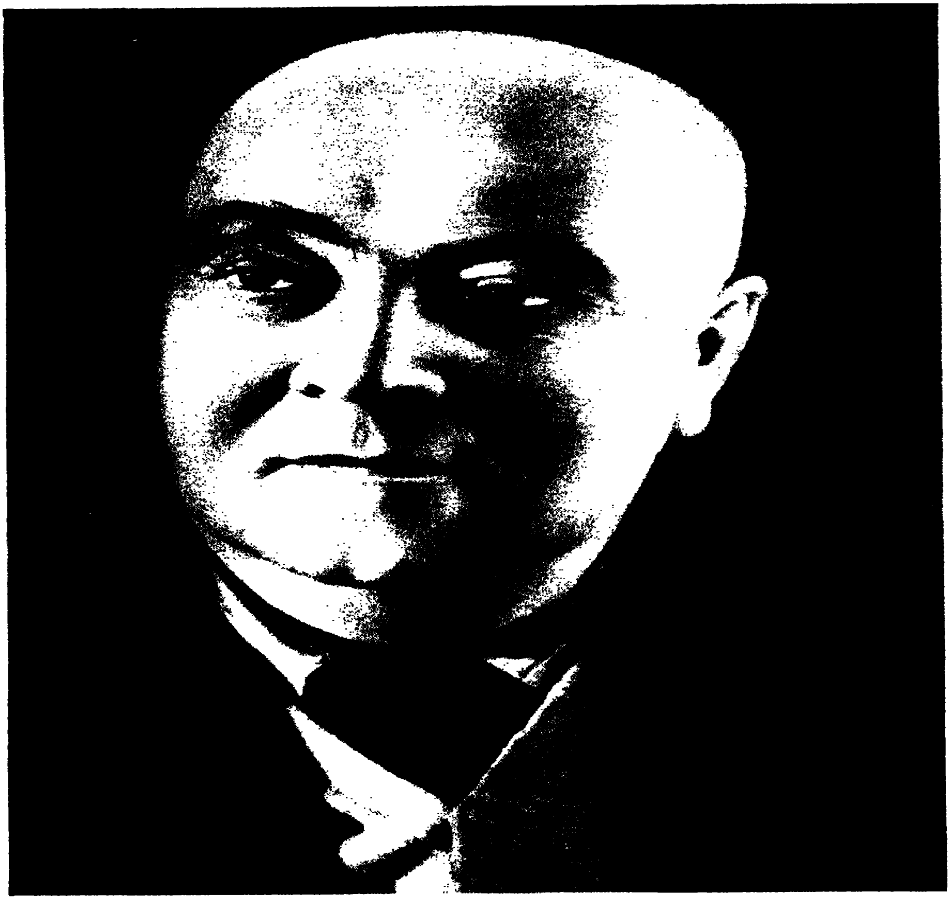

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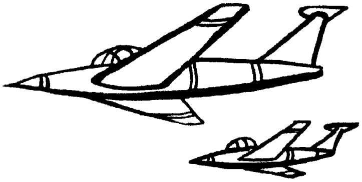

A. Fersman

GEOCHEMISTRY for EVERYONE

FOREIGN LANGUAGES PUBLISHING HOUSE
Moscow 1958

TRANSLATED FROM THE RUSSIAN BY
DAVID A. MYSHNE

DESIGNED BY G. DAUMANN

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FOREWORD

In the book *Geochemistry for Everyone* Academician A. Fersman offers an entertaining account of the many years of work he devoted to developing geochemistry, the new branch of geological science, and strives to show the chemical life of our planet as it appeared to his imagination enriched by extensive scientific experience.

This new branch of science about the earth came into being in the beginning of our century and is set forth in the works of the outstanding Soviet scientists – Academicians V. Vernadsky and A. Fersman.

It took a lot of work and time before general ideas of the chemical composition of the earth's crust could emerge from the separate and isolated observations. The progress made by nuclear physics and chemistry, the sciences about the structure of matter, helped the geologist and mineralogist to get a clear insight into the distribution and cycle of matter in the earth's crust. Man was able to grasp the unity of processes which take place in the minutest particles of matter, i.e., atoms and molecules, and in its tremendous universal condensations, i.e., the suns and the remotest stars.

The science of geochemistry was coming into being, a science which leads us into the field of accomplishments made by chemical physics, cosmic chemistry and astrophysics and which, at the same time, subjoins the achievements of these sciences to the problems of studying minerals.

Alexander Fersman was an enthusiast of geochemistry, one who had a profound understanding of its significance to the economic and cultural life of the country.

He won wide popularity with the Soviet youth by his ardent love of science and life which inspired him in writing the remarkable popular-science books for the young people; the best of these books include his *Mineralogy for Everyone* and *Geochemistry for Everyone*.

It is a matter of regret that the author was unable to finish his *Geochemistry for Everyone* and some chapters had to be completed by his friends and pupils.

Thus, the chapters "World of the Invisible" and the "Atom Disintegrates" were written by Academician V. Khlopin, the chapters "Carbon" and "Atoms in Water" were contributed by Academician A. Vinogradov, while the chapter

"Rare Dispersed Elements" belongs to the pen of Professor V. Shcherbina. Materials compiled by A. Fersman were used in the chapter "From the History of Geochemical Ideas," written by Academician D. Shcherbakov, and "Atoms in the History of Mankind," presented by Professor N. Razumovsky.

The book was first published in 1948 under the general scientific editorship of Professor N. Razumovsky with Academician V. Khlopin acting as consultant. They did all they could to bring the book as close to A. Fersman's own idea as possible.

A. Fersman is widely known as an outstanding mineralogist, geochemist and geographer, as a persistent explorer of the mineral resources of the U.S.S.R., as a tireless traveller and a brilliant popularizer of geological knowledge.

He was born in St. Petersburg in 1883. The future scientist spent his childhood in the Crimea where he learned to love the science about stones. "The Crimea was my first university," the Academician used to say.

The youth, who was at first attracted by the external beauty of stones, gradually became interested in questions of their composition and origin.

After graduation from secondary school A. Fersman studied at Moscow University where he attended lectures on mineralogy and worked under the supervision of Academician Vladimir Vernadsky.

Before Vernadsky mineralogy was taught at the university as a dry and tedious subject. The mineralogists of the end of the 19th century mainly described the minerals, studied their crystallographic forms and systematized them.

Vernadsky brought a breath of fresh air into this descriptive mineralogy. He began to regard minerals as products of natural (terrestrial) chemical reactions and took an interest in the conditions under which they had formed, i.e., their birth, their life and their transformation into other minerals.

This was no longer the old mineralogy which indifferently described the wonders of the earth's entrails. The young researchers had new passions and new ideas. They were not merely mineralogists, but chemico-mineralogists. "That was how our teacher taught us," A. Fersman later recalled. "He combined chemistry with nature and chemical thinking with the methods of a naturalist. It was a school of new natural science based on the exact data furnished by the science about the chemical life of the earth." The scientific work was done more in the field than in the seclusion of university studies and laboratories. Excursions and expeditions, which were later recalled by A. Fersman time and again, formed part and parcel of learning.

Time wore on. Knowledge was acquired through hard work. The young scientists studied day and night sometimes staying in the university building for days on end.

A. Fersman was graduated from Moscow University in 1907, but even as an undergraduate he had written five scientific papers on problems of crystallography, chemistry and mineralogy under V. Vernadsky's supervision. For these papers he was awarded the Antipov Gold Medal, granted to young scientists by the Mineralogical Society.

At the age of 27 Alexander Fersman was elected professor of mineralogy and in 1912 he began to teach a new subject—geochemistry—for the first time in the history of science.

In his lectures A. Fersman especially emphasized that "... We must be chemists of the earth's crust. We must study not only the distribution and formation of minerals, these temporarily stable combinations of elements, but also the very elements, their distribution, their transitions and their life."

The same year marked the beginning of A. Fersman's uninterrupted, lifelong activities in the Russian Academy of Sciences, first in Petersburg and then in Moscow.

The Great October Socialist Revolution set up entirely new and favourable conditions for scientific research. Unlimited opportunities to exercise all his creative abilities opened up before Fersman in studying and investigating the natural productive forces of the country.

Profound and penetrating investigator as he was, A. Fersman was one of the staunchest and most ardent supporters of applied activity; he never ceased to summon the scientists into the field of practical, national-economic interests.

In 1919, at the age of 35, A. Fersman was elected member of the Academy of Sciences of the U.S.S.R. and at the same time appointed Director of the Mineralogical Museum of the Academy of Sciences.

In appraising Fersman's creative life we cannot but be surprised at the variety of his scientific and practical interests and extraordinary efficiency. In developing the scientific principles of geochemistry and mineralogy he considered field research of prime importance. He took a very active part in expeditions and visited the most diverse regions of the country—the Khibiny tundra on Kola Peninsula, flourishing Ferghana Valley, the hot Kara-Kum and Kizyl-Kum sands in Central Asia, the vast taiga spaces in the Baikal and the Trans-Baikal regions, the wooded eastern slopes of the Urals, Altai, the Ukraine, the Crimea, the North Caucasus, Transcaucasia, etc.

Of exceptional interest are the truly heroic explorations of Kola Peninsula begun by A. Fersman in Khibiny in 1920 and in the Moncha tundra in 1930 and continuing to the very end of his life.

His greatest achievement was the discovery of apatite and nickel-ore deposits of world importance.

As a result of extensive work done by A. Fersman and other specialists Kola Peninsula has given the country some of the richest deposits of numerous minerals.

Industrial exploitation of the resources of Kola Peninsula began in 1929. The remote and at one time scarcely-known wilderness in the distant North has changed into a most important mining and industrial region. New cities, at first Khibinogorsk (now Kirovsk) and soon afterwards Monchegorsk and others, have arisen in the uninhabited areas as if by magic.

Here is what A. Fersman himself wrote about the work on Kola Peninsula:

"In the midst of all experiences of the past, amid the various pictures of nature, man and economy, the most vivid in my life were the impressions of the Khibiny, a whole scientific epos which for nearly twenty years occupied my mind, consumed my efforts and energy, took full possession of my being, sharpened my will, my scientific thinking, my desires and my hopes.... Only by stubbornness and persistence, only by tremendous work were we able to achieve results in this wonderland which revealed its riches to us as though in a fairy-tale." The Khibiny period does not overshadow Fersman's other scientific research. He had enough energy for everything.

In 1924 Fersman began his work in Central Asia and his interest in this work continued to the end of his life. In 1925 he ventured a daring trip to the central Kara Kum, barely known at the time, and studied a rich deposit of native sulphur which has become the property of Soviet industry. The sulphur plant built with his aid is still working today.

Between 1934 and 1939 A. Fersman finished his capital four-volume work *Geochemistry* on the chemistry of the elements of the earth's crust, a work remarkable for its force and scientific foresight. In this work, based on the laws of physical chemistry, which brought A. Fersman and, in his person, Russian geochemistry world fame, he made an extensive analysis of the regularities of migrations of atoms in the earth's crust.

In 1940 Fersman finished his *Minerals on Kola Peninsula*. In this work he gave a brilliant example of a geochemical approach to the study of mineral resources and predicted the discovery of a number of new mineral deposits.

A. Fersman has left us an enormous literary heritage. He published close to 1,500 articles, books and large monographs. In addition to the works on crystallography, mineralogy, geology, chemistry, geochemistry, geography and aerial photography he wrote on astronomy, philosophy, art, archaeology, soil science, biology, etc.

Alexander Fersman was not only a scientist, but a public figure and statesman as well.

Special mention must be made of him as a talented writer and popularizer of geological knowledge, a "poet of stones," as A. Tolstoi called him.

His reports, lectures and personal chats inspired and fascinated his listeners of all ages and occupations, while his numerous popular-science articles were read by all sections of the population.

The first edition of *Mineralogy for Everyone* appeared in 1928; the book was translated into many foreign languages and has run into 25 editions. *Recollections about a Stone* was published in 1940. *My Travels*, *Stories about Precious Stones* and *Geochemistry for Everyone* came out of print after A. Fersman's death. All these books have made him very popular with readers of all ages.

Such books do not come into being all of a sudden. They are a result of long years of creative work and experience; they reflect the entire life of the scientist and his scientific interests. At the same time these are books of an experienced and talented teacher who appreciates the problems of educating the rising scientific generation. With his fervent words of a writer and speaker A. Fersman kindled the love for mineralogy and geochemistry in legions of young people and led a large number of scientific workers to new studies and research.

Fersman's great love for his native land should be particularly emphasized. This love is felt in everyone of his statements, in each line of his writings. All his essays are hymns to labour, calling to mastery and to creative transformation of the country's nature on the basis of exact scientific knowledge.

"We do not want to be photographers of nature, the earth and its riches," Fersman used to say. "We want to be investigators and creators of new ideas;

we want to conquer nature and to subordinate it to man, to his culture and economy.

"We do not want to be merely accurate observers or impassive tourists who jot down their impressions in a note-book. We want to get a deep insight into nature so that our profound and thoughtful investigation of it may not only give rise to ideas, but also result in deeds. We cannot be merely idle admirers of our vast country; we must actively help reshape it and create a new life."

Life without work and science had no meaning to Fersman. The more difficult the task he faced the greater the zeal with which he tackled it.

A. Fersman died after a grave illness in 1945.

"The services rendered by A. Fersman to science and to our country are immeasurable and immortal," said Academician D. Belyankin. "The scope of his scientific interests combined with his untiring concern for the well-being and glory of our country quite remind us of our immortal Lomonosov and Mendeleyev. It is no accident that he held these names so sacred."

Academician *D. Shcherbakov*

INTRODUCTION

Several years ago I wrote my *Mineralogy for Everyone*. Since then I have received hundreds of letters from school children, workers and various specialists. The letters show so much genuine and lively interest in stones, their study and the history of their use. Some of the children's letters displayed a good deal of youthful fervour, vim and vigour.... The letters have fascinated me and I have decided to write another book for our rising generation.

Of late I have been working in a different, a much harder and much more abstract field; my thoughts have lured me away into a remarkable world, a world of infinitely small, negligible particles of which all of nature and man himself are made.

In the last twenty years I have chanced to take part in developing a whole new science, which we call *geochemistry*. It was not in comfortable study-rooms with pen and paper in hand that we developed this science; it came into being as a result of numerous accurate observations, experiments and measurements; it was born in the struggle for a new understanding of life and nature, and beautiful, indeed, were the moments when the separate new chapters of this science of the future were brought to an end.

But what will I tell you about geochemistry that may entertain you? What kind of a science is it? And why is it not simply chemistry, but *geochemistry*? And then why is it not a chemist, but a geologist, a mineralogist and a crystallographer who writes about it?

The reader will not get the answer to his questions in the first chapter; he will learn a good deal in it, but briefly. Only he who reads the book to the end will get a real insight into geochemistry and will actually enjoy it.

The reader will then say: "So that is geochemistry! What an interesting and difficult science it is! How little chemistry, geology and even mineralogy I know as yet to get a real grasp of it!"

But it is worth your while learning more about it because the future of geochemistry is much more important than some people believe, for it is precisely geochemistry that will, together with physics and chemistry, place the great resources of matter and energy under the command of man.

Before bringing this introduction to an end I should like to advise the reader how to read this book. It is not enough to tell what to read: it is often even more important to tell how to read and study a book in order to get the most out of it. Some books are read avidly because the interesting story fascinates the reader and he cannot tear himself away from it. That is the way, for example, adventure stories are read. Other books must be studied because they either contain a whole science or treat separate scientific problems; in these books scientific data are consistently presented, natural phenomena are described and scientific inferences are drawn. When reading such books one must delve into every word without skipping a single page or even line or word.

But our book is neither a fascinating novel nor a scientific treatise. It is built according to a special plan. One after another its four parts pass from general problems of physics and chemistry to problems of geochemistry and its future. The reader who is not well versed in the fundamentals of these sciences must read this book slowly and carefully and, perhaps, even reread the difficult pages or those that are of special interest to him. But if the reader knows physics and chemistry he may skip separate parts of the book which deal with problems familiar to him; the author has endeavoured to make each essay complete and as far as possible independent of the other parts. The book is also of value to those who wish to get a deeper insight into chemistry or geology.

Students will find it very useful to read separate chapters while studying a general course of chemistry because each of these chapters may in large measure illustrate some particularly dry pages in the textbook of chemistry.

While studying the non-metals the reader may concurrently peruse the chapter on phosphorus and sulphur; in investigating the ferrous metals the student would do well to familiarize himself with the chapter on iron and vanadium.

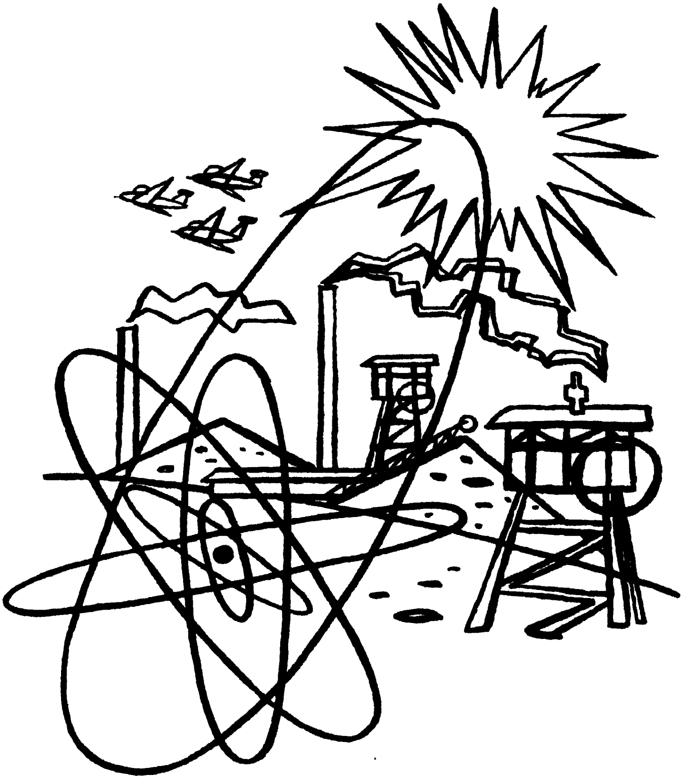
In studying geology the student should similarly make use of corresponding chapters which throw light on the big chemical problems of the distribution of elements in the earth's crust. Of particular interest in this respect are the chapters devoted to the description of the earth's crust, especially Part Three entitled "History of the Atom in Nature."

Those who study chemistry will see that I have dealt with but few chemical elements; I have given a more or less detailed description of only fifteen of them. But then it has never been my intention to give a full chemical description and history of all the chemical elements in the universe, in the earth's crust, on the surface of the earth and in the hands of man.

I wanted to elucidate only individual and most essential features in the "behaviour" of the most ordinary and useful elements which live their complicated chemical life around us and amid the unnoticeable and continuous chemical processes of the earth. I am sure many pages could be written about each chemical element. The reader himself may wish to write the history of some element about which I have not said anything. It seems to me this might prove a useful practical task, and if someone takes an interest in a lump of metal chromium, its fate, its deposits and its role in industry, and pursues this course he may write many interesting pages from the history of this element and shed light on the behaviour of this little member of the big iron family.

I can only advise the careful readers who have studied this book and who are interested in problems of extensive analysis of nature to venture such a task and to continue the pages I have written about the most important elements on the earth.

PART ONE

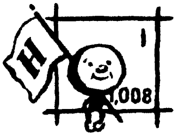


THE ATOM

WHAT IS GEOCHEMISTRY?

What is geochemistry? This is the first question we must answer if we are to understand all this book is going to deal with.

We know what geology is because it teaches us about the earth, its crust, its history and the changes it undergoes; it tells us how mountains, rivers and seas are formed, how volcanoes and lava make their appearance and how sediments of silts and sands slowly grow on the ocean floor.



We also understand mineralogy which studies minerals.

In my book *Mineralogy for Everyone* I wrote: "A mineral is a natural compound of chemical elements which has formed without the interference of man. It is a sort of edifice built of different quantities of certain bricks; it is not a disorderly pile of these bricks, but a structure made according to certain laws of nature. We understand very well that even by using the same bricks and in the same quantities we can put up different buildings. The same mineral may similarly be encountered in nature in most diverse forms though it essentially remains the same chemical compound.

"We count about one hundred varieties of these bricks of which all of the nature that surrounds us is built.

"These chemical elements include gases—oxygen, nitrogen and hydrogen; metals—sodium, magnesium, iron, mercury, gold or such substances as silicon, chlorine, bromine, etc.

"Various combinations of elements in different amounts give us what we call minerals; for example, chlorine and sodium give us common salts, two parts of oxygen and one part of silicon yield silica or quartz, etc.

Crystals of smoky quartz in feldspar

"... Three thousand different minerals (quartz, salt, feldspar, etc.) have thus been built of combinations of various chemical elements in the earth and these minerals, accumulating together, form what we call rock (for example, granite, limestone, basalt, sand, etc.).

"The science that studies minerals is called mineralogy, the one that describes rocks is known as petrography, while geochemistry investigates the very bricks we have been talking about and their wanderings in nature. . . ."

Geochemistry is still a young science and it has come to the fore mainly owing to the work of Soviet scientists.

Its tasks consist in tracing and ascertaining the fate and behaviour of the chemical elements in the earth, the elements which constitute the basis of surrounding nature and which, if arranged in a certain order, make up D. Mendeleyev's remarkable periodic system.

The fundamental unit of geochemical research is the chemical element and its atom.

As a rule, each box in Mendeleyev's table contains one chemical element—the atom—and has its ordinal or atomic number. The first number belongs to the lightest element—hydrogen, while the heaviest 92nd element is called uranium and it is 238 times as heavy as hydrogen.

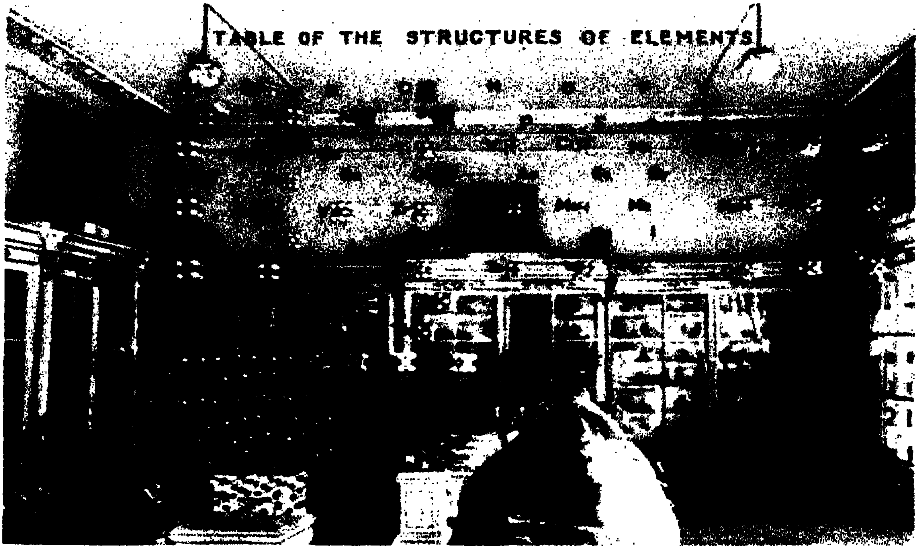
The atoms are very small and, if we picture them as little balls, each atom will have a diameter of 0.0000001 mm. But the atoms in no way resemble solid little balls; they are a more complicated system consisting of an atomic nucleus with particles of electricity—electrons—moving around them, the number of electrons varying in different atoms.

In structure, therefore, atoms rather resemble sub-microscopic solar systems with a central sun—the nucleus—and planets—the electrons—moving around it.

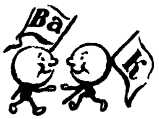
The number of electrons varies with the different kinds of atoms (chemical elements), owing to which they differ in their chemical properties. By exchanging their electrons the atoms combine and form molecules.

Mendeleyev's table shows a number of natural families of elements which are encountered together not only in the table, but also in nature.

The importance of Mendeleyev's system consists precisely in the fact that it is not a theoretical scheme, but an expression of the natural relationships between the separate elements which determine their similarities, their differences, their shifts and the paths of their migrations in the earth. In a word, Mendeleyev's Periodic Table is also a geochemical table which, as a reliable compass, helps the geochemist in his prospecting.



Cristalline structures of the chemical elements as arranged in the Mendeleyev table. The arrangement of the balls shows how the atoms are distributed in a simple solid body. In the foreground (left) we see a diagram of distribution of silicon and oxygen atoms in quartz. (Exposition at the Museum of the Leningrad Mining Institute)



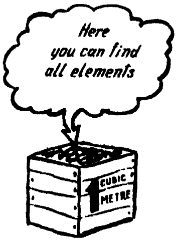
New ideas are born wherever the mindful scientist applies Mendeleyev's Law to the analysis of natural phenomena.

But what is geochemistry anyway? What is this new science that has lately attracted so many young investigators?

As the term itself shows geochemistry studies the chemical processes which occur in the earth.

Chemical elements as independent units of nature shift, wander and combine, or, as we say, they migrate in the earth's crust; the laws governing the combinations of elements and minerals at different pressures and temperatures in various portions of the earth's crust are just the problems on which modern geochemistry is working.

Some chemical elements (for example, scandium and hafnium) are incapable of forming accumulations and sometimes are so dispersed that the rock contains only 0.00000001 per cent of these chemical elements.


Here you can find all elements
CUBIC METRE

We might call these elements super-dispersed and we extract them only when they are of some special value to practice.

We now believe that all elements of Mendeleyev's Periodic Table can be found in every cubic metre of rock if only our methods of analysis detect them with sufficient accuracy. We must not forget that in the history of science new methods are of even greater importance than new theories.

Contrariwise, other elements (for example, lead and iron) in their continuous migration make a number of stops, as it were, form compounds in which they easily accumulate and persist for a long time. Despite the complex changes in the earth's crust throughout geological history these elements retain the forms of their accumulation, form large concentrations and prove accessible to industrial exploitation.

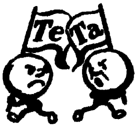
Geochemistry studies the laws of distribution and migration of the elements not only in the earth and in the universe as a whole, but also under certain geological conditions and in certain regions of the country as, for example, in the Caucasus and in the Urals, and indicates where minerals should be prospected for.

Thus, the profound theoretical principles of modern geochemistry come ever closer to practical problems, and on the basis of a number of general principles geochemistry strives to show where a certain

"Levy Talgar" Canyon in the Trans-Ili Ala-Tau. Kazakh S.S.R.

chemical element may be found, where and under what conditions we may expect to encounter accumulations, for example, of vanadium or tungsten, what metals would "more willingly" be found together as, for instance, barium and potassium, and what elements will "avoid" each other as, for example, tellurium and tantalum.

Geochemistry studies the behaviour of every element, but to judge this behaviour it must have good knowledge of the properties of the element, of its peculiarities, of its inclination to combine with other elements or, on the contrary, to separate from them.



The geochemist, thus, becomes an explorer and prospector, he suggests the parts of the earth's crust where iron or manganese ores can be found, tells us where we can discover deposits of platinum amid serpentines and explains why; he advises the geologist to look for arsenic and antimony in young geological rocks and mountain ranges, and predicts failure if they search for these metals where the conditions for their concentration are lacking.

Young geochemist examining an outcrop in the Kara-Shor Depression. Turkmen S.S.R.

But all this is possible when the "behaviour" of the chemical element has been thoroughly studied, just as by studying the behaviour of a person in life it is possible not only to explain his actions but also to predict what he will do under different circumstances.

This is where the tremendous practical importance of this new science comes in!

Geochemistry, as we see, marches shoulder to shoulder with geology and chemistry.

* * *

I do not want to overburden you with a mass of facts, examples and calculations, nor am I undertaking to teach you all there is to know about geochemistry. No, I only want you to take an interest in this new science, which was born but very recently, so that you may convince yourselves from reading the separate essays on the wanderings of elements throughout the world that geochemistry is still a young science and that the future holds wide prospects for it, but that it must also win this future.

Like everywhere in life, progress and truth do not immediately win in the world of scientific ideas: they have to be fought for; they require a mobilization of all forces, great purposefulness and energy, a conviction of worthiness and a faith in victory.

It is not the abstract, barren and inactive idea that wins, but the fighting idea, the idea which burns with the flame of new quests, the idea deeply rooted in life and its problems.

A vast field for research lies before the chemists of the earth in the Soviet Union.

We still need an enormous number of facts and we need them, as the great Russian scientist Ivan Pavlov said, like a bird needs air to support its wings.

The bird and the plane, however, are kept in the air not only by the air itself, but primarily by their own onward movement.

It is the same onward movement that supports any science; the science survives only through persistent creative work and the fires of its daring quests simultaneously combined with a cool and sober analysis of its achievements.

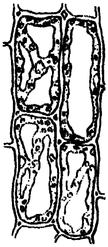
Industry is still far from using all the elements, and we must continue to work hard and persistently before we place all the elements in Mendeleyev's Periodic Table at the service of mankind.

WORLD OF THE INVISIBLE. THE ATOM AND THE CHEMICAL ELEMENT

Let me have your hand, reader, and I shall take you into the world of very small things which we do not usually notice. Here is a laboratory of magnification and diminution. Let us go in. We are expected there. This ordinary-looking man in work clothes is not yet old, but he is a famous inventor. Let us hear what he has to say.

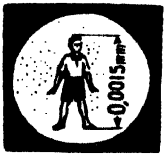
"Let us go into the cabin; it is made of material transparent to rays of any wave-length, including the shortest cosmic rays. I shall turn the lever to the right and we will begin to grow smaller. This process of growing smaller is not very pleasant; according to the stop-watch we grow 1,000 times as small every four minutes. We shall stop in four minutes, leave the cabin and see the surrounding world as it is seen through the best microscopes. Then we shall return to our cabin and try to grow another 1,000 times as small."

Well, we have turned the lever....



We have grown smaller, we have become as small as ants.... We hear things differently now, because our ear no longer reacts to the air waves.... Only noises, buzzing, crackling and rustling reach our senses. But we have retained our sight because in nature there are X-rays with a wave-length 1,000 times as short as that of light. The appearance of things has changed most unexpectedly; most bodies have become very transparent and even the metals are brightly coloured and look like stained glass.... But then glass, resin and amber have grown dark and now look like metals.

We see plant cells filled with a pulsating juice and grains of starch, and if we want to we can put our hand into the stoma of a leaf; blood corpuscles as large as a farthing float in a drop of blood and tubercular bacilli look like bent nails without a head.... The bacteria of cholera resemble small beans with fast beating tails.... But we cannot see molecules, and only an incessant shaking of the walls and a light pricking of the face by the air, as though a wind were blowing dust into the face, remind us that we are approaching the limit of divisibility of matter....



We return to the cabin and move the lever one more point. Everything has turned dark around us, and our cabin has begun to shake as in an earthquake.

As we regain our senses, the cabin is still shaking and we feel as if a hail storm were raging around us; we are continuously showered by something like peas and we get the impression we are fired upon by a thousand machine-guns....

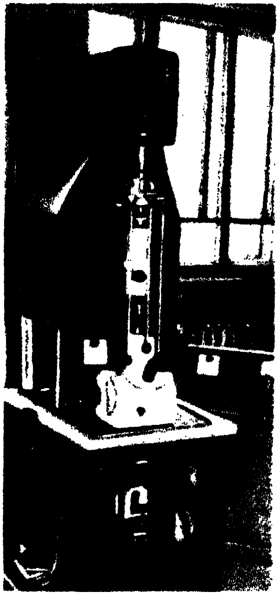
Our guide suddenly speaks up:

"We cannot leave the cabin. We are one million times as small as we were; we now measure thousandths of a millimetre, only one and a half microns in fact.

"Our hair is now 0.00000001 centimetre thick; this magnitude is called 'angström' and serves to measure molecules and atoms. The molecules of the gases of the air have a diameter of about one angström. These molecules are now travelling at a tremendous speed and are bombarding our cabin.

"When we left the cabin the first time we felt as if a wind were blowing dust into our faces; this was the action of individual molecules. Now that we have become smaller their movements are as dangerous to us as a shot of sand is to man.

"Look out of the window and you will see a dust particle one micron in diameter, that is nearly as small as we are ourselves. See how it is buffeted about by the unequal blows it receives from the whirl of molecules! I regret we cannot see them because they move too fast.... But it is time we were going back: the ultra-short waves in the



Electronic microscope magnifying up to 500,000 times. The object is illumined by a stream of electrons; electromagnets serve as lenses rays of which we are examining the molecules are harmful to our eyes."

At these words our guide turns the lever back....

Of course, our trip was only imaginary, but the picture we have painted is very close to reality.

Experience shows that whatever we do to perfect the methods of analysis, as a result of analyzing complex bodies we come to a number of simple substances which cannot be chemically divided into still simpler constituents.

All these simple bodies, which cannot be divided any more and of which all the bodies of surrounding nature are made, we call chemical elements.

In continuous contact with the various bodies of nature, living and dead, solid, liquid and gaseous, man has arrived at one of his most important generalizations: the idea of substance, of matter. What are the properties of this matter and what is its structure? These are the questions that anyone who studies nature must ask himself.

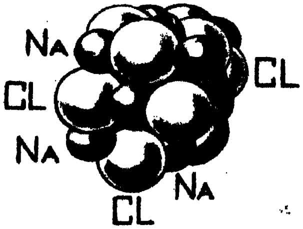
The first answer we get by direct sensation is the apparent continuity of substance. But this impression is only an illusion. By using a microscope we often discover a porosity in substance, i.e., the existence of small spaces invisible to the naked eye.

But even in such substances as water, alcohol and other liquids, as well as gases, in which it would seem there should be no pores as a matter of principle, we must recognize the existence of intervals between the particles of matter or else we could never understand why substances can condense under pressure and expand by heating.

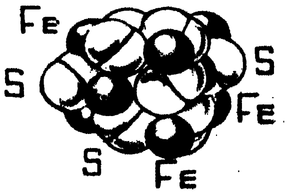
All matter is granular. The smallest granules of substance are called atoms or molecules. We have managed to calculate, for example, that in liquid water the molecules occupy only about one-third or one-fourth of the space. The rest is taken up by pores.

Today we know that when atoms approach each other certain forces of repulsion arise and the atoms cannot merge. Around each atom we can describe a "sphere of impermeability" beyond which no other matter can penetrate under usual conditions. We may, therefore, regard the atoms together with these spheres as elastic globules impermeable to each other. Each element has a sphere of impermeability the radius of which is expressed in angströms. For example, in carbon it is 0.19 angström, in silicon—0.39, i.e., small; in iron it is 0.83 and in calcium—1.06, i.e., medium; in oxygen it is 1.40, i.e., large (see diagram on page 57 where the elements are presented in the form of circles proportional to the size of the radii of their spheres).

But if we pack balls into a container (for example, a box) the disorderly placed balls will occupy a greater volume than when packed in an orderly manner. The packing which occupies the smallest volume is called the densest packing. It can be obtained, for example, in the following experiment: take several dozen steel balls (from a ball-bearing), place them on a saucer and tap the saucer lightly. Since the balls will try to get to the centre of the saucer they will crowd each other and will soon arrange themselves in rows with 60° angles in between. On the outside they will arrange themselves along the sides of a rectilinear hexagon. This will be the densest packing of balls of one size on a plane.



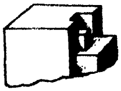
Model of the structure of rock salt–NaCl



Model of the structure of pyrite–FeS_2

Such is the arrangement of the atoms of many metals—copper, gold, etc.

If the balls are unequal (for instance, of two sharply differing sizes) it often happens that the larger balls (for example, chlorine in the crystals of common salt) yield the densest packing, while the smaller atoms arrange themselves in the spaces between the large balls.



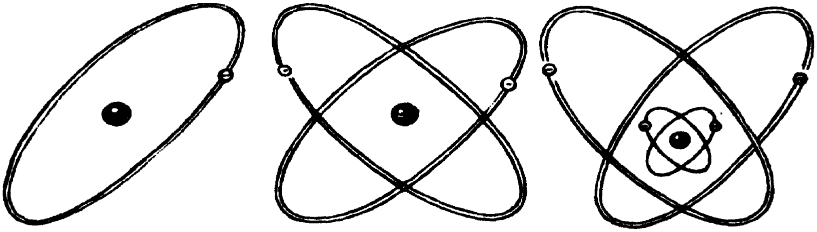
Thus, in common salt (or halite)—NaCl—one atom of sodium is surrounded on six sides by atoms of chlorine, while each atom of chlorine is surrounded on six sides by atoms of sodium. Under these conditions the forces of attraction between the ions of sodium and chlorine are the greatest.

Now then, the bodies that surround us, regardless of their complexity or simplicity, consist of a combination of minutest particles, or atoms, invisible to the naked eye, just like a beautiful large building is made of separate small bricks.

This thought was born in hoary antiquity, and we encounter the idea of "atom" (indivisible, in Greek) in the Greek materialist philosophy of Leucippus and Democritus who lived 600-400 B. C. According to modern concepts, the basis for which was laid as early as the 19th century, a chemical element in a free state and in the form of a simple body consists of an aggregate of homogeneous atoms which are no longer divisible at least without losing the individual properties inherent in the given substance.

The atoms of the same chemical element are uniform in structure and have a characteristic mass or an atomic weight.

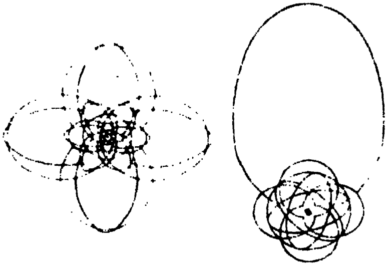
In the beginning of our century scientists knew there should be 92 different elements on earth and, hence, 92 types of different atoms. Of these 92 chemical elements we have thus far been able to find and isolate from natural objects 90 chemical elements and, correspondingly, 90 types of atoms, but we do not doubt that the unfound elements also exist. All the bodies of nature known to us are built of combinations of these 92 types of atoms.

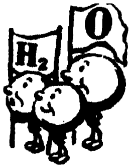


The structure of hydrogen, helium and beryllium atoms. The circumferences show the orbits of the electrons; the nuclei of the atoms are in the centre

Uranium, the heaviest of all elements known to us until recently, has number 92.

Recent studies in disintegration of uranium elements have revealed still heavier transuranium elements: neptunium 93, plutonium 94, americium 95, curium 96, berkelium 97, californium 98, einsteinium 99, fermium 100 and mendelevium 101. The existence of even heavier atoms is not surprising, but all these atoms are very unstable and do not occur in nature, but are produced artificially; we shall not be making any particular mistake if in studying the composition of the natural bodies of the earth we proceed from the conjecture that all of them are made up of 92 elements.


Structure of sodium and krypton atoms



Atoms of the same element, like those of different elements, by combining with each other in twos or more, may form molecules of various substances. By combining with each other the atoms and molecules build all of the existing natural bodies. The number of atoms and molecules must be very large. For example, if we take 18 grams of water, a so-called gram-molecule, it will contain 6.06×10^{23} molecules of water.

This is a colossal number; it is many thousand times the number of grains of wheat and rye that have grown on the earth since the existence of vegetation.

In order to get an idea about the size of a molecule let us compare it with the minutest of living organisms, a bacterium, which can be seen only through a microscope when magnified about a thousand times. The size of the smallest bacteria is 0.0002 millimetre. And even this is a thousand times the size of a water molecule, which means that even the smallest bacterium contains more than two thousand million atoms, i. e., more than there are people on earth.

A chain of the water molecules contained in three drops of water would stretch from the earth to the sun and back nearly six times because it is 9,400,000,000 kilometres long.

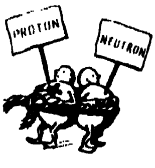
The atom was originally conceived as a minutest indivisible particle, but on closer investigation, as our methods of research were improved and rendered more accurate, it turned out to be a very complex structure. The nature of the atom was vividly revealed for the first time when people learned of the phenomena of radioactivity and began to study them.

Each atom contains a nucleus with a diameter about 0.00001 that of the atom. The nucleus practically contains its entire mass. It carries a positive electric charge which increases as we proceed from the lighter chemical elements to the heavier ones. Around this positively charged nucleus revolve electrons whose number equals the number of positive charges in the nucleus so that the atom as a whole is electrically neutral.

The nuclei of the atoms of all chemical elements consist of two simplest particles—a proton or hydrogen atom nucleus and a neutron, i. e., a particle with a mass which almost exactly equals the mass of the proton but is devoid of any electric charge. The protons and neutrons in the nuclei of the atoms are so firmly bound up with each other that the nuclei of the atoms remain absolutely invariable and stable in all chemical reactions and under all physical forces.

Especially stable is the combination of the two protons and two neutrons which form the nucleus of helium atom. The nucleus of helium is so stable that in the atoms of the heavy elements it is, apparently, contained in its ready-made form and flies out as an alpha particle during the radioactive disintegration of the nuclei.

The chemical properties of elements depend on the structure and properties of the external shell of the atoms and on the ability of the atoms to lose or gain electrons. The structure of the nucleus of the atom hardly affects the chemical properties of the latter. Atoms which have the same number of external electrons, even if the structure of their nuclei and their mass or atomic weight differ, therefore, have the same chemical properties and form kindred groups of atoms as, for example, chlorine, bromine, iodine and the like.



The diagrams show various models of atomic structure in which the reader can see how complicated the electron orbits become as the atoms increase in weight.

THE ATOMS AROUND US

Look at the three pictures we are printing in this chapter.

A wonderful view of a mountain lake with a blue mirror-like surface surrounded by limestone cliffs, dark-green spots of solitary trees, and above all this the bright southern sun.

A noisy iron and steel works enveloped in smoke and steam and belching fire; trainloads of ore, coal, flux and brick running to the mill and returning with hundreds of tons of rails, blanks, ingots and rolled metal to the new centres of industry.

ZIL-110; a smart car; the dark-green varnish shines on its fenders and you can almost hear the purring of its motor and the soft melody issuing from its radio-receiver. This car was assembled from thousands of parts on the long conveyer of the plant and will now easily run hundreds of thousands of kilometres.

Look at these three pictures and tell me frankly what you are thinking about as you look at them, what you have taken a fancy for and what question you would like to ask.

I am divining your thoughts and your questions because you are living in an age of engineering and industry and your interests are bound up with the machines that create power and the power that creates machines.

But I should like to tell you about something else so that you may see these pictures through different eyes. Now you listen.

* * *

I know what the geologist will say to me. "Just think of the remarkable scientific geological problems this lake contains! How was this enormous,

Mountain lake in Tajikistan

deep gap formed? What forces have locked these blue waters amid the steep spurs of the Tajik mountains? There are between two and three thousand metres from the top of the mountains to the bottom of the lake; what mighty power could have raised and crumpled the layers of rock?"

The mineralogist will say: "What wonderful limestone is formed by these cliffs and mountains! It must have taken scores and hundreds of millenniums for this powerful sediment of silt, shells and testae to accumulate on the ocean floor and be compressed into dense limestone, almost into marble! Take an ordinary mineralogical magnifying glass which magnifies ten times and you will hardly discern the individual shiny crystals of lime spar of which the rock is made."

"How white and pure this limestone is!" the chemical technologist will interrupt him. "This is excellent raw material for the cement industry and for roasting into lime; it is almost pure calcium carbonate, a combination of atoms of calcium, oxygen and carbon dioxide. Look, I shall dissolve it in a weak acid; the calcium will dissolve and the carbon dioxide will come off with a hiss."

"But we could perform even more exact experiments," the geochemist will say. "We can prove with the aid of a spectroscope that this limestone contains other atoms as well; it has strontium, barium, aluminium and silicon. And if we make a super-precision analysis and try to find the rarest atoms of which there is less than one-millionth of one per cent here we shall be able to discover even zinc and lead in this limestone.

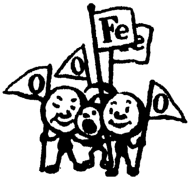
"And don't think this is a specific feature of our limestone because experienced chemists will find 35 different types of atoms even in the world's purest marble.

"Now we are even inclined to believe that we should be able to find all the elements of the Mendeleyev Periodic Table in every cubic metre of stone—granite or basalt, limestone or clay—only the amount of some of these will be one-trillionth that of calcium or carbon."

The words of the geologist, mineralogist, chemist and geochemist will impress you so much that instead of simple greyish limestone you will see mountains of some mysterious stone and you will want to get a deeper insight into its nature and discover the secret of its origin and being.

* * *

Now let us turn to the works. What strange buildings, unusual in size and shape! Giant towers filled with ore, coal and limestone; enormous pipes lead to these towers and feed them compressed hot air. What for? Why is metal smelted in them, why is coal burned and why do clouds of heated gases flare up as they leave these towers?

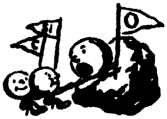


You will probably be surprised if I tell you that this is a laboratory of atoms; in the ore the atoms of iron are very firmly tied to each other by larger balls—oxygen atoms—which do not let the iron atoms get closer to each other and give us the heavy malleable metal we call iron.... Iron ore possesses none of the properties of this metal though it contains 70 per cent of it. We must, therefore, drive the oxygen out. But this is not so easy to do.

Do you remember, dear reader, the Russian fairy-tale about the little girl Alyonushka who had to pick out all the grains of sand out of a pile of corn? Do you remember that she called on her little friends, the ants, and that they succeeded with this task? But then those were grains of sand with a diameter a million times that of the oxygen atom! I know you will say: "This is a hard job and I scarcely believe it can be done." To be sure, it took a lot of work and human energy to solve this brain-teaser.

But it was solved just the same!

In this case the human genius did not call upon ants, but on atoms of other substances. And in alliance with the natural elements fire and wind it made these atoms take the oxygen away from the iron and bring it with the hot air to the surface of the metal boiling in the furnace.



But who are these atomic friends that have vanquished oxygen? There are two of them — silicon and carbon. Both of them seize oxygen, hold it much faster than iron and build very strong structures with it. And they help one another. While burning, carbon takes the oxygen away from the iron and develops a tremendous temperature; it could not do the whole job by itself, however, because the hard iron ore is refractory and not very mobile, and the atoms of carbon cannot penetrate into the dense lumps of ore.

This is when silicon comes to the aid: small and tenacious it yields fusible slags, dissolves the ore, takes away the oxygen and hands it over to the carbon. Part of the carbon dissolves in the iron and makes it mobile and fusible.

At this time the elements step in: the fire increases the mobility of the iron, all that is light rises to the surface together with the gases, all that is heavy settles to the bottom, and behold the miracle: the atoms have separated — the iron with the dissolved carbon takes its place at the bottom of the furnace, while the light slags which have carried off all of the ore's oxygen float on the surface of the melted metal and can be easily thrown out.

Imagine the knowledge that had to be accumulated, the insight into the habits and whims of each atom that had to be acquired for man to be able unmistakably to sort the atoms at will on so grand a scale!

* * *

Let us now take a look at the third picture the Soviet automobile ZIL-110. It is also a combination of atoms picked for a single purpose, i.e., to produce an untiring, powerful, noiseless and fast car.

Metallurgical plant

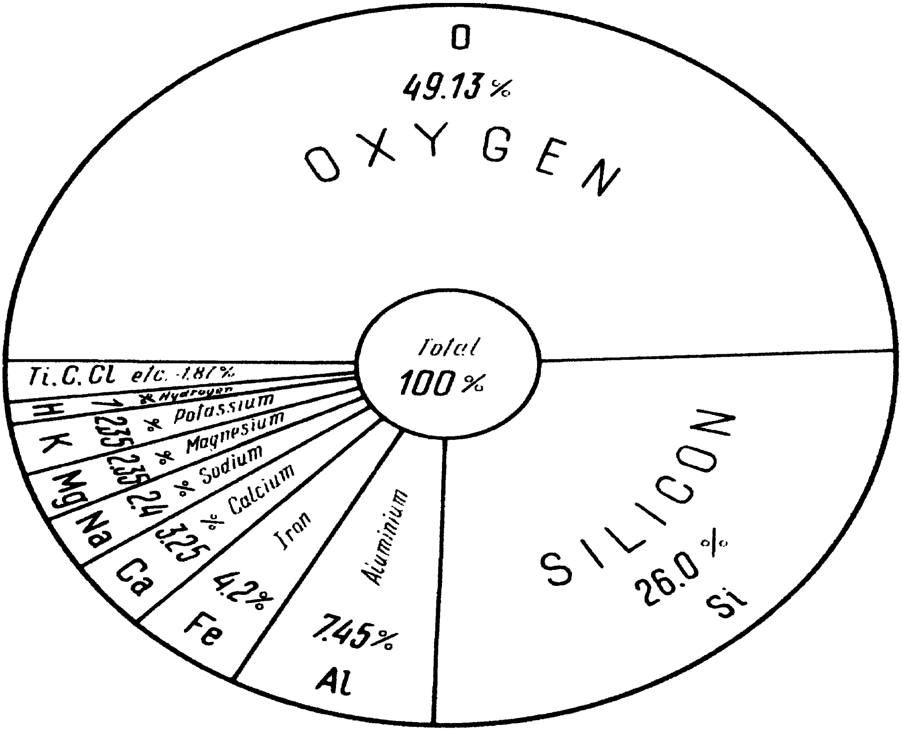
Thousands of parts made of 65 kinds of atoms and at least 100 grades of metal—that's what ZIL-110 is! It has a lot of iron, but iron whose properties have been changed 100 different ways; here is pig iron, an iron alloy containing 4 per cent carbon; this is the iron from which the body of the motor was cast. But here is an iron in which less carbon was left, and the result is a hard and elastic steel. Now some atoms of manganese, nickel, cobalt and molybdenum, which resemble iron, were added to it and the steel has become elastic, durable and shockproof. Then some vanadium was added and the steel has become as pliable as a whip; tireless springs are made of this steel.

It is no longer copper, but aluminium that now holds second place in the car; the pistons and knobs, the graceful bodies, the plating and bands—all that can be made light is made of aluminium or its alloys with copper, silicon, zinc and magnesium.

And how about the best porcelain used in the manufacture of automobile sparkplugs? And what about the varnish that fears no rain or cold, the woollens, the copper in the wiring, the lead and sulphur in the batteries? Enough, or we shall not find a single element that

ZIL-110 passenger car built by the Moscow Likhachov Motor Works does not travel with the car. Combining with each other they form more than 250 different substances and materials which are directly or indirectly used in the automobile industry.

It should be emphasized that here man disregards the natural processes, breaks them and subordinates them to his own will. Is it at all natural for aluminium to be free? No, a thousand times no; and if it were not for the genius of man this would never happen even if the earth existed many more millions of years.



Weight content of elements in the earth's crust (down to a depth of 16 km.)

Having understood and learned the properties of atoms man has taken advantage of his knowledge and shifts the elements as he sees fit. The light elements are the most widespread in the earth; five of them—oxygen, silicon, aluminium, iron and calcium—make up 90.03 per cent of the earth's crust. If we add seven more—sodium, potassium, magnesium, hydrogen, titanium, carbon and chlorine—these twelve elements will constitute 99.29 per cent. The remaining 80 elements hardly make up 0.7 per cent by weight. But this distribution does not suit man who stubbornly searches for the rare elements, extracts them from the earth, at times with incredible difficulties, makes an all-round study of their properties and uses them wherever necessary and expedient. That's why we find nickel (of which the earth contains 0.02 per cent), cobalt (which forms 0.001 per cent), molybdenum (less than 0.001 per cent) and even platinum (which constitutes 0.000000012 per cent of the elements) in the automobile.

The atoms are all around, and man is their master. He takes them with his masterful hand, mixes them, casts away the ones he has no use for and combines those he needs, though without him these elements should never meet. And while the mountain lake in Tajikistan glorifies the powerful natural elements which have raised the cliffs and created the gaps, the mill and automobile are an industrial symphony about the might of the human genius, about human labour and knowledge.

BIRTH AND BEHAVIOUR OF THE ATOM IN THE UNIVERSE

I remember a lovely and quiet night in the Crimea. It seemed all nature had gone to sleep and nothing disturbed the smooth surface of the placid sea. Even the stars did not twinkle in the black southern sky, but shone brightly. Silence reigned all around and it seemed the world had ceased moving and stood still in the infinite calm of the southern night.

But how far this picture is from reality and how deceptive the peace and quiet of surrounding nature!

Suffice it to begin dialing a radio-receiver to find that the world is pierced by myriads of electromagnetic waves. Now several metres, now thousands of kilometres long, the stormy waves of world ether rise to the height of the ozone strata and pounce upon the earth again. Piling up on top of each other they fill the world with oscillations imperceptible to the unaided ear.

And the stars which appear so immovable in the firmament rush through world space at the terrific speed of hundreds and thousands of kilometres per second. One sun-star heads in one direction of the galaxy carrying away streams of bodies invisible to the eye; others whirl at an even faster rate and create enormous nebulae; still others speed into unknown regions of the universe.

Vapours of incandescent substances rush through the stellar atmosphere with a velocity of thousands of kilometres per second, and it takes only several minutes for immense gaseous clouds measuring thousands of kilometres to appear and to form glittering prominences in the corona of the sun.

The melt is boiling in the immeasurable depths of the distant stars. The temperature there runs as high as scores of millions

Evening on the Crimean seashore near Alupka

of degrees; individual particles break away from one another, the nuclei of the atoms burst, streams of electrons rush to the upper layers of the stellar atmospheres, while powerful electromagnetic storms travel thousands of millions of kilometres, reach our earth and disturb the calm of its atmosphere.

The cosmos is filled with oscillations, and Lucretius Carus, one of the greatest scientists of the past, beautifully said almost one hundred years B. C.:

"... no rest, we may be sure, is allowed to the first-bodies moving through the deep void, but rather plied with unceasing, diverse motion, some when they have dashed together leap back at great space apart, others too are thrust but a short way from the blow."

Our earth is also living its life. Its quiet and seemingly silent surface is really replete with vital activity. Millions of minutest bacteria populate each cubic centimetre of the soil. Extending the possibilities of research the microscope reveals new worlds of even smaller living beings, the constantly moving viruses, and the question now is whether they should be considered living beings or remarkable molecules of inanimate nature.

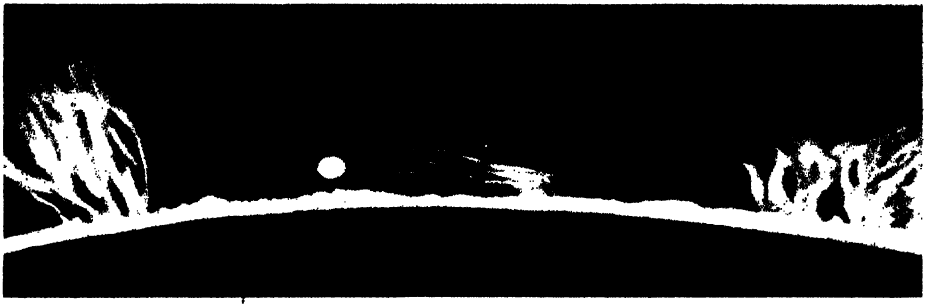
The molecules shift eternally in the thermal movements of the sea, and scientific analysis shows that each oscillation in sea-water travels a long and complicated course at speeds measured in kilometres per minute.

The air and the earth eternally exchange atoms. Atoms of helium vaporize from the depths of the earth's crust into the air; the velocity of their movement is so high that they overcome gravity and fly away into interplanetary space.

The mobile atoms of oxygen enter the organisms from the air; molecules of carbon dioxide are broken up by plants thus creating a continuous carbon cycle, while molten heavy rocks are still boiling in the interior of the earth and are trying to break through to the surface.

A clear and transparent crystal lies before us hard and motionless. It would seem that the individual atoms of the substance were distributed through strictly fixed units of some invariably strong lattice. But this is only apparent: the atoms are in constant motion, revolving around their points of equilibrium, continuously exchanging their electrons now free as in the atoms of a metal and now bound; and they move along complexly recurring orbits.

Everything is alive around us. The picture of the quiet evening in the Crimea is deceptive, and the more our science masters nature the wider the real picture of all the movements of the world substance



Protuberances on the sun during the eclipse of May 28, 1900. White circle shows size of the earth on the same scale; its diameter is 12,750 km.

that surrounds us opens up before us. And when science learned to measure motion which occurs in millionths of a second, when it began with its new Roentgen "hands" to measure millionths of a centimetre with an accuracy with which we cannot even use our yardstick, and when it learned to magnify the pictures of nature 200,000 and 300,000 times and brought within man's vision not only the minutest viruses, but even individual molecules of substance, it dawned on us that there was no calm in the world, but only a chaos of constant movements which seek their temporary equilibrium.

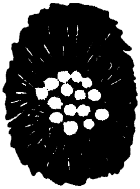
Heraclitus

Once upon a time, very long ago, even before the heyday of ancient Greece, there lived a remarkable philosopher whose name was Heraclitus. With his perspicacious mind he was able to penetrate into the very depths of the universe, and he said the words which Herzen called the most brilliant words in human history.

Heraclitus said: "Everything is fluid," and made the idea of eternal motion the basis of his world system. With this idea humanity has gone through all the stages of its history. It was on this idea that Lucretius Carus built his philosophy in the remarkable poem on the nature of things and the history of the world. The brilliant Russian scientist Mikhail Lomonosov built his physics with rare perspicacity on this idea, saying that each point in nature has three movements: translational, rotatory and oscillatory. And now that the new achievements of science have confirmed this old philosophic idea we must take a new view of the surrounding world and the laws of matter.

The laws of distribution of atoms will be for us the laws of the infinitely complex movements of different velocities, different directions and different scales which determine the multiformity of the surrounding world, the diversity of its restless atoms. Today we are beginning to get a new insight into space.

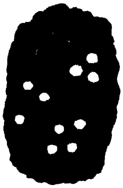
The part of the universe accessible to our observation is colossal. It cannot be measured in kilometres, for this is too small a unit. Even the distance of 150 million kilometres between the sun and the earth, which light traverses in eight and one-third minutes, is also too small a unit, though light can travel seven and a half times around the earth in one second. Scientists have invented a new unit, the "light year," i. e., the distance light traverses in one year. The best telescopes can make out stars from which it takes light millions of years to reach us. The cosmos is really infinite, but as far as we are concerned its limits are set by the resolving power of our telescopes.



Clusters of stellar matter in space form local condensations and give rise to what we call the visible world. There are approximately one hundred thousand million of these worlds. Each of these worlds also contains about one hundred thousand million stars and each star is made up of 1 and 57 noughts (10^{57}) of protons and neutrons, i.e., the minutest particles of which the whole world is composed, not counting the even smaller particles of electricity, the negatively charged electrons.

Hydrogen is the most abundant element in the universe. We know a large number of cosmic nebulae composed almost entirely of hydrogen. The atoms of hydrogen accumulate attracted by gravitation and impelled by specific interatomic forces, the study of which has only just begun. Powerful clusters consisting of a number of atoms expressed by a figure of 56 digits arise and a new star makes its appearance. But the dimensions of the universe are infinitely great compared with the volume of the atoms which have come into being. We know that the greater part of the universe is actually a sort of void containing only from 10 to 100 particles, i.e., atoms of substance, per cubic metre, and this corresponds to a rarefaction which is 10^{27} that of the normal atmospheric pressure on earth. Here rarefied spaces are found side by side with absolutely unprecedented condensations produced by pressure in the interiors of stars where thousands of millions of atmospheres are combined with scores or hundreds of millions of degrees of heat; this is the natural laboratory where hydrogen gives rise to new and heavier atoms, primarily helium.

In the stars shining with a dazzling white light as, for example, the famous satellite of Sirius, the substance is so dense that it is a thousand times as heavy as gold and platinum. We can even hardly imagine what this substance is and what properties it has.



On the one hand, we have infinite interplanetary spaces traversed by the freely flying single atoms. Here world rest is in dialectical unity with precipitate movement, and a temperature of almost absolute zero reigns.

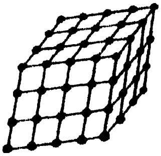
On the other hand, we have the central regions of the stars where millions of degrees of heat are combined with pressures of millions of atmospheres and where the atoms, having overcome the repulsion of the electrons, are knitted into a single dense mass of substances never seen on earth. Under these conditions the evolution of chemical elements takes place, and the elements are the heavier and denser the greater the mass of the star and the higher the pressure and temperature in its interior.

The chemical element which comes into being is the first step in the struggle against chaos. Heavier nuclei may be formed from free protons and electrons at enormous temperatures and pressures.

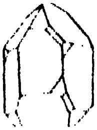
Various structures, which we call chemical elements, thus gradually arise in different places. Some of them are heavier and have more energy, others are light and consist of only a few protons and neutrons. These lighter elements are carried away in streams to the periphery of the stars, into their atmospheres or combine into immense world nebulae. Others, which are less mobile, remain on the surface of incandescent or molten bodies.

Nebula M-101 in the constellation of the Big Dipper

Powerful radiations destroy some structures and build others; some elements disintegrate while others are created anew until the ready-made atoms find themselves where there are no forces strong enough to destroy their stable nuclei. This is when the history of the wanderings of individual atoms through the universe begins. Some of them fill the interplanetary spaces as, for example, the atoms of calcium and sodium, which in their free flight traverse the entire



universe. Others, which are heavier and stabler, accumulate in various parts of the nebulae. Temperatures drop, electrical fields of atoms combine with each other and molecules of simple chemical compounds are formed; these include carbides, hydrocarbons, particles of acetylene and some substances unknown on earth which the astrophysicists observe on the incandescent surfaces of distant stars as the first product of atomic combinations. These simple free molecules gradually give rise to more and more harmonious systems. At low temperatures, outside the destructive fields and cosmic depths, the second step in the world order — the crystal — is finally born. A crystal is a remarkable structure where the atoms are arranged in a certain *orderly* relation to each other, like building-blocks in a box. The birth of a crystal is the next stage in the process of the emergence of matter from chaos. 10^{22} individual atoms combine to form a cubic centimetre of crystalline substance. New properties, the properties of crystals, make their appearance. Now it is no longer the laws of the electromagnetic clusters of which they are composed, not the yet unknown laws of nuclear energy that govern, but new laws of matter, the laws of chemistry.



I shall not continue the description of this picture. I only wanted to show that we have very little knowledge of the world that surrounds us, that this world is uncommonly complex and its calm is only apparent because it is replete with *motion*; matter as we know it here on earth, as we see it in hard stone in surrounding nature, comes into the world in a whirl of motion. Much of what I have said has already been demonstrated by modern science, but a good deal of how first the atom and then the crystal come into being from world chaos is as yet a mystery to us.

And still, how beautifully this picture was painted by Lucretius Carus, the Roman philosopher, two thousand years ago! Let us recall a few lines from his poem:

"But only a sort of fresh-formed storm, a mass gathered together of first-beginnings of every kind, whose discord was waging war and confounding interspaces, paths, interlacings, weights, blows, meetings, and motions, because owing to their unlike forms and diverse shapes, all things were unable to remain in union, as they do now, and to give and receive harmonious motions. From this mass parts began to fly off hither and thither, and like things to unite with like, and so to unfold a world, and to sunder its members and dispose its great parts. . . ."

And so there is no rest in nature; everything changes even if at different rates. Stone, the symbol of durability, also changes because the atoms of which it is composed are in eternal motion. To us it appears firm and motionless only because we do not see this motion the results of which become perceptible a long time afterwards, whereas we ourselves change much faster.

It was long believed that only the atom was indivisible, invariable and indifferent to eternal change. But lo and behold! atoms, too, are heedful of time. Some of them, we call them radioactive, change fast; others change slowly. Moreover, we know now that atoms also evolve, that they are created in the heat of the stars, that they develop and die. . . .

And the human mind reflects the same eternal motion and development: at first incomprehension, chaos and lack of order. Then the types of connections between all parts of the world begin to grow clear, the movements prove subject to laws, and a harmonious picture of an indivisible universe presents itself to man. Such is the world as modern science reveals it to us.

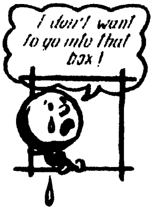
HOW MENDELEYEV DISCOVERED HIS LAW

In the old building of the chemical laboratory of Petersburg University sat a young though already well-known professor. It was Dmitry Mendeleyev. He had just been appointed head of the department of general chemistry at the university and was busy drawing up a study plan for his students. He was thinking of how he might most conveniently set forth the laws of chemistry, describe the history of the separate elements and proceed with the course of study. He was wondering how he might connect his stories about potassium, sodium, lithium, iron, manganese, nickel, etc. He already had a feeling the separate chemical atoms were in some way related to each other though these relations were not clear as yet.

In order to find the best possible arrangement he took separate cards and wrote in big letters the name of an element, its atomic weight and some of its chief properties on each card. Then he began to arrange these cards by grouping the elements according to their properties about the way our grandmothers used to arrange their cards when playing patience.

Suddenly the professor observed a remarkable regularity. He had arranged his chemical elements one after another in the order of increasing atomic weights and discovered that with but few exceptions the properties of the elements recurred at certain intervals. He then began to lay out more cards below the first row and after placing seven elements started on the third row.

In this row he had to put already seventeen elements in order that the elements showing any similarities be arranged one below another, but somehow it did not come out quite right and he had to leave gaps. Seventeen more cards made another row. It was getting more compli-


I don't want to go into that box!

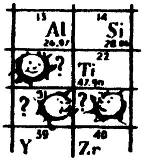
cated; several atoms just would not fit though the recurrence of properties was clearly observed.

All the elements known to D. Mendeleyev were, thus, arranged in the form of a table and with but few exceptions they all followed each other in horizontal rows in the order of their increasing atomic weights, while the similar elements found themselves arranged in vertical columns.

In March 1869, D. Mendeleyev sent the first brief report on his law to the Physico-Chemical Society in Petersburg. Then, sensing the enormous importance of his discovery, he began working persistently, correcting his table and making it more exact. He soon found blanks in the table.

"New substances will soon be found for these blank spaces following silicon, boron and aluminium," he would say. His predictions soon came true and the newly discovered elements named gallium, germanium and scandium were placed in the vacant squares of the table.

One of the greatest discoveries in the history of chemistry was, thus, made by the Russian chemist D. Mendeleyev. But don't think it is so simple, my friends; that all you have to do is take cards, write names on them, arrange them in a certain order and the thing is done. This simplicity, this chance discovery, as it were, is only apparent. Only 62 elements were known at that time. The atomic weights were determined inaccurately, some of them wrongly, and the properties of the atoms were but little known. Man had to get an insight into the nature of each chemical substance, grasp the similarities between some of the elements, divine the course of each element's migrations, the "friendship" or "hostility" of the elements in the earth itself.



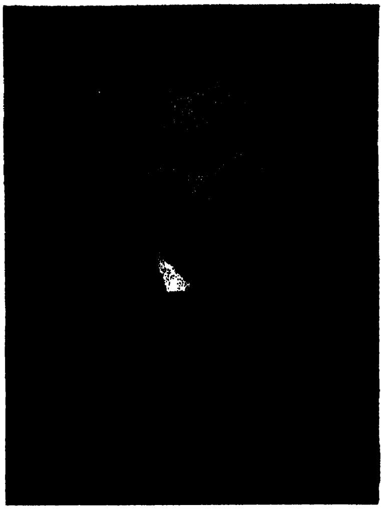
D. Mendeleyev succeeded in knitting into a single whole all that had been known of the chemistry of the earth before him.

To be sure, there were also other scientists who noticed a relationship between the elements though their ideas about it were still vague and imperfect.

But most scientists of that time thought the idea of kinship between the elements absurd. Thus, when the English chemist Newlands, one of the fighters for the freedom of Italy in Garibaldi's army, submitted to the press a paper on the recurrence of the properties of certain elements with an increase in their atomic weights his paper was rejected by the Chemical Society and one of the chemists tried to ridicule

Newlands by saying he might have arrived at an even more interesting conclusion if he had arranged all the elements in alphabetic order.

But all these were only particulars. Science still needed a lot more: it had to draw up a single plan, a fundamental law of the universe, and show by facts that this law was valid everywhere, that all the properties of each element were governed by this law, were subject to it and had their source in it.



D. Mendeleyev. Photograph made in 1869

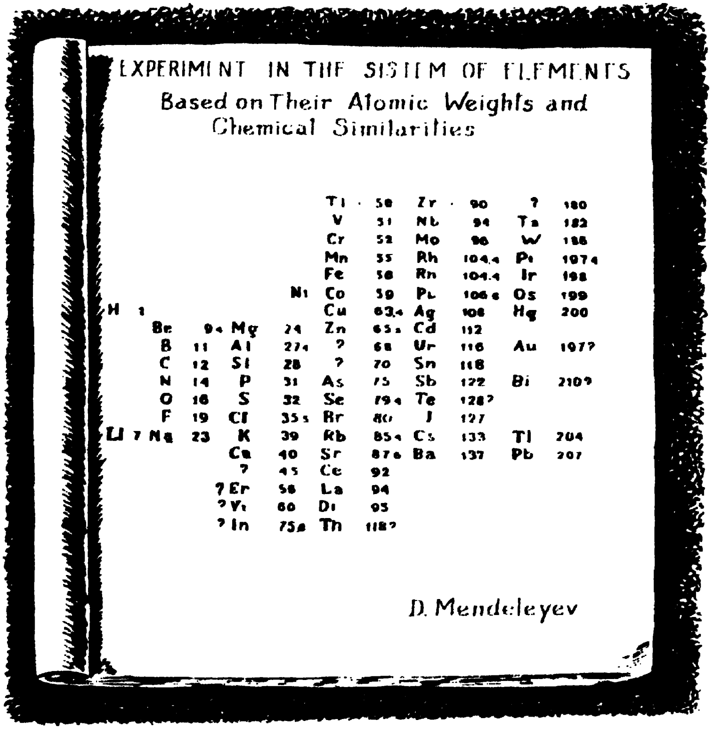
This required intuition of a genius, ability to see what was common to the elements, despite the discrepancies, and persistence in investigating concrete facts. D. Mendeleyev proved equal to the task.

He was able to show the interrelations of all the atoms in nature so clearly, distinctly and simply that nobody could disprove his system. The order had been found. True enough, the bonds which linked these elements with each other were still a mystery, but the order was so obvious that it enabled Mendeleyev to speak of a new natural law—the Periodic Law of chemical elements.

Many years have elapsed since then. D. Mendeleyev worked on this law for nearly 40 years penetrating into the deepest mysteries of chemistry.

In the Chamber of Weights and Measures, which he headed, he studied and measured the various properties of metals, by most accurate methods, finding ever more confirmation of his discovery.

He travelled through the Urals studying its resources and devoted many years to the problem of oil and its origin; everywhere, in the laboratory and in nature, he found confirmation of his Periodic Law. In the profoundest theories and in industry this law was being transformed into a guiding compass which directed the searches of scientists and men of practice like a compass guides the seafarers at sea.



EXPERIMENT IN THE SYSTEM OF ELEMENTS
Based on Their Atomic Weights and
Chemical Similarities

						Ti	50	Zr	90	?	180
						V	51	Nb	94	Ta	182
						Cr	52	Mo	96	W	186
						Mn	55	Rh	104.4	Pt	197.4
						Fe	56	Rn	104.4	Ir	198
						Ni Co	59	Pl	106.6	Os	199
H	1					Cu	63.4	Ag	108	Hg	200
		Be	9.4	Mg	24	Zn	65.2	Cd	112		
		B	11	Al	27.4	?	68	Ur	116	Au	197?
		C	12	Si	28	?	70	Sn	118		
		N	14	P	31	As	75	Sb	122	Bi	210?
		O	16	S	32	Se	79.4	Te	128?		
		F	19	Cl	35.5	Br	80	J	127		
Li	7	Na	23	K	39	Rb	85.4	Cs	133	Tl	204
				Ca	40	Sr	87.6	Ba	137	Pb	207
				?	45	Ce	92				
				?Er	56	La	94				
				?Yt	60	Di	95				
				?In	75.6	Th	118?				

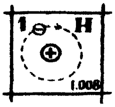
D. Mendeleyev

The periodic system of elements. The original table produced by D. Mendeleyev in 1869

D. Mendeleyev corrected and improved his little table of 1869 until the very last days of his life; hundreds of chemists, following in his footsteps, discovered new elements and new compounds gradually divining the profound inner meaning of Mendeleyev's table.

Today we see it in an entirely new light.

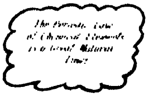
D. Mendeleyev's Periodic Table proved an excellent guide to the study of the regularities of the structures of atomic spectra. While studying the spectra of elements arranged in the order of Mendeleyev's Periodic Table Henry Moseley, young British physicist, quite unexpectedly discovered one more regularity in Mendeleyev's Periodic Table in 1913, and ascertained the important role of the atomic numbers of elements.



He proved that the most important part of the element was the charge on the central nucleus which exactly equals the element's atomic number. It equals one in hydrogen, two in helium, thirty in zinc and ninety-two in uranium; just as many electrons are tied by these charges to the nucleus and rush around the latter in their orbits.

In every atom the number of electrons surrounding the nucleus equals the atomic number of the element. All electrons are very definitely arranged in separate layers. Layer K, first and closest to the nucleus, contains one electron in hydrogen and two electrons in all the other elements. The second layer L contains eight electrons in most atoms. Layer M may have up to 18 electrons, layer N up to 32.

The chemical properties of atoms are determined mainly by the structure of the outermost electron layer which is particularly stable when the number of electrons in it reaches eight. The atoms with one or two electrons in their outermost layer easily give them up and change to ions. For example, sodium, potassium and rubidium have one electron each in their outermost layers. They lose them very easily and change to univalent positively charged ions. Under the circumstances the next electron layer becomes the outer layer. This layer contains 8 electrons which ensures the stability of the ion-atom.



The atoms of calcium, barium and other alkaline-earth metals have two electrons in their outermost layers each, upon losing which they become stable bivalent positive ions. The atoms of bromine, chlorine and other halogens have seven electrons in their outermost layers. They greedily capture electrons from the outermost layers of other atoms and by repleting their own outermost layers to eight electrons become stable negative ions.

The elements with three, four and five electrons in their outermost layers display a lesser tendency to form ions in chemical reactions.

The weight of the atom and the frequency of its occurrence in nature depend on the structure of its nucleus, while its chemical properties and spectrum are dependent on the number of its electrons and are extraordinarily similar in elements with like structures of the outermost electron layers.

Such is the mystery of the atom. Since this mystery was revealed chemists and physicists, geochemists and astronomers, technicians and technologists have recognized Mendeleyev's Periodic Law as one of the profoundest laws of nature.

D. I. MENDELEYEV'S PERIODIC

PERIODS	SERIES	ELEMENT				
		I	II	III	IV	V
1	I	H 1 1.0080 1				
2	II	Li 3 6.940 1 2	Be 4 9.013 2 2	5 B 10.82 3 2	6 C 12.011 4 2	7 N 14.008 5 2
3	III	Na 11 22.991 1 8 2	Mg 12 24.32 2 8 2	13 Al 26.98 3 8 2	14 Si 28.09 4 8 2	15 P 30.975 5 8 2
4	IV	K 19 39.100 1 8 8 2	Ca 20 40.08 2 8 8 2	Sc 21 44.96 2 9 8 2	Ti 22 47.90 2 10 8 2	V 23 50.95 2 11 8 2
	V	29 Cu 63.54 1 18 8 2	30 Zn 65.38 2 18 8 2	31 Ga 69.72 3 18 8 2	32 Ge 72.60 4 18 8 2	33 As 74.91 5 18 8 2
5	VI	Rb 37 85.48 1 8 18 8 2	Sr 38 87.63 2 8 18 8 2	Y 39 88.92 2 9 18 8 2	Zr 40 91.22 2 10 18 8 2	Nb 41 92.91 1 12 18 8 2
	VII	47 Ag 107.880 1 18 18 8 2	48 Cd 112.41 2 18 18 8 2	49 In 114.76 3 18 18 8 2	50 Sn 118.70 4 18 18 8 2	51 Sb 121.76 5 18 18 8 2
6	VIII	55 Cs 132.91 1 8 18 18 8 2	56 Ba 137.36 2 8 18 18 8 2	57 La ★ 138.92 2 9 18 18 8 2	72 Hf 178.6 2 10 32 18 8 2	73 Ta 180.95 2 11 32 18 8 2
	IX	79 Au 197.0 1 18 32 18 8 2	80 Hg 200.61 2 18 32 18 8 2	81 Tl 204.39 3 18 32 18 8 2	82 Pb 207.21 4 18 32 18 8 2	83 Bi 209.00 5 18 32 18 8 2
7	X	87 Fr [223] 1 8 18 32 18 8 2	88 Ra 226.05 2 8 18 32 18 8 2	89 Ac ★★ 227 2 9 18 32 18 8 2	(Th)	(Pa)

★ LANTHA

58 Ce 140.13 2 8 20 18 8 2	59 Pr 140.92 2 8 21 18 8 2	60 Nd 144.27 2 8 22 18 8 2	61 Pm [145] 2 8 23 18 8 2	62 Sm 150.43 2 8 24 18 8 2	63 Eu 152.0 2 8 25 18 8 2	64 Gd 156.9 2 9 25 18 8 2

★★ ACTI

90 Th 232.05 2 10 18 32 18 8 2	91 Pa 231 2 9 20 32 18 8 2	92 U 238.07 2 9 21 32 18 8 2	93 Np [237] 2 8 23 32 18 8 2	94 Pu [242] 2 8 24 32 18 8 2	95 Am [243] 2 8 25 32 18 8 2	96 Cm [245] 2 9 25 32 18 8 2

Figures in square brackets are mass numbers of stablest isotopes

TABLE OF ELEMENTS

GROUPS

VI	VII	VIII			0
	(H)				**He** 2 4.003 2
O 8 16 6 2	**F** 9 19.00 7 2				**Ne** 10 20.183 8 2
S 16 32.066 6 8 2	**Cl** 17 35.457 7 8 2				**Ar** 18 39.944 8 8 2
Cr 24 52.01 1 13 8 2	**Mn** 25 54.94 2 13 8 2	**Fe** 26 55.85 2 14 8 2	**Co** 27 58.94 2 15 8 2	**Ni** 28 58.69 2 16 8 2	
Se 34 78.96 6 18 8 2	**Br** 35 79.916 7 18 8 2				**Kr** 36 83.80 8 18 8 2
Mo 42 95.95 1 13 18 8 2	**Tc** 43 [99] 2 13 18 8 2	**Ru** 44 101.1 1 15 18 8 2	**Rh** 45 102.91 1 16 18 8 2	**Pd** 46 106.7 0 18 18 8 2	
Te 52 127.61 6 18 18 8 2	**I** 53 126.91 7 18 18 8 2				**Xe** 54 131.3 8 18 18 8 2
W 74 183.92 2 12 32 18 8 2	**Re** 75 186.31 2 13 32 18 8 2	**Os** 76 190.2 2 14 32 18 8 2	**Ir** 77 192.2 2 15 32 18 8 2	**Pt** 78 195.23 1 17 32 18 8 2	
Po 84 210 6 18 32 18 8 2	**At** 85 [210] 7 18 32 18 8 2				**Rn** 86 222 8 18 32 18 8 2
(U)					

NIDES

Tb 65 158.93 2 8 27 18 8 2	**Dy** 66 162.46 2 8 28 18 8 2	**Ho** 67 164.94 2 8 29 18 8 2	**Er** 68 167.2 2 8 30 18 8 2	**Tu** 69 168.94 2 8 31 18 8 2	**Yb** 70 173.04 2 8 32 18 8 2	**Lu** 71 174.99 2 9 32 18 8 2

NIDES

Bk 97 [245] 2 8 27 32 18 8 2	**Cf** 98 [248] 2 8 28 32 18 8 2	**En** 99 [253] 2 8 29 32 18 8 2	**Fm** 100 [255] 2 8 30 32 18 8 2	**Mv** 101 [256] 2 8 31 32 18 8 2	

Atomic number

Electron layers

Atomic weight

Symbol

MENDELEYEV'S PERIODIC SYSTEM OF ELEMENTS IN OUR DAYS

Investigators have proposed many different methods whereby the characteristic features of Mendeleyev's Periodic Table might be revealed as clearly and distinctly as possible.

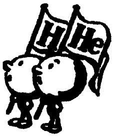
Some illustrations in this book show how Mendeleyev's great law was represented at different times, now as bands and columns now as a twisted spiral on a plane, and now as a complicated pattern of lines and arcs.

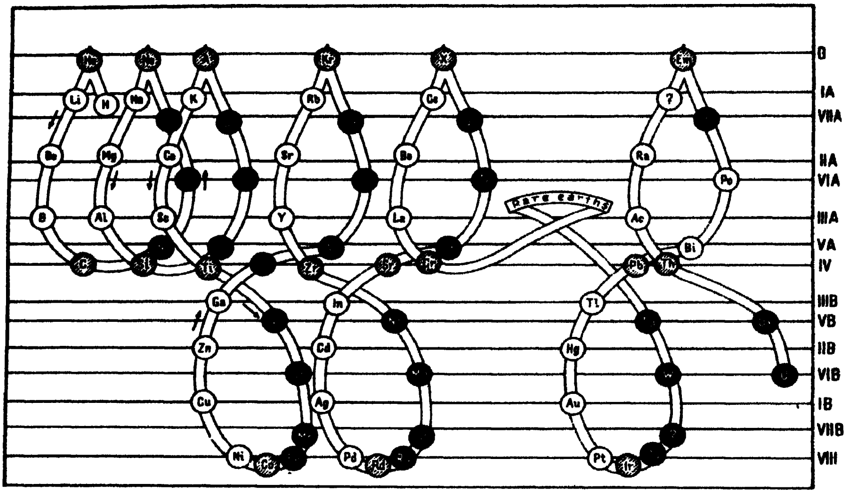
We shall come back to the attempt at setting the table forth in the form of a grand spiral later, but now we shall present it as it is presented by modern science.

Let us look into this table and try to make out what it really means.

In the first place we see a big number of squares or boxes which are arranged in seven horizontal rows (or periods) and in eighteen vertical columns or, as the chemists call them, groups. Incidentally, let us immediately observe that in most textbooks this table is given in a somewhat different form (the rows appear doubled, as it were), but we shall find it more convenient to analyze it the way it is.

The first period contains only two elements hydrogen (H) and helium (He); the second and third periods contain eight chemical elements each; there are 18 chemical elements in each of the fourth, fifth and sixth periods. The boxes of these six periods should be occupied by 72 elements; it turns out, however, that 14 elements similar to lanthanum, so-called lanthanides, are inserted between box 57 and box 72. Finally, the last period contains, apparently like the preceding one, 32 boxes but only some of them are occupied as yet.





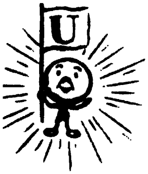
The Mendeleyev's periodic system of elements as represented by Soddy (1914). Horizontal lines show series of elements with similar chemical properties. Big periods are shown in the form of eights (8). White circles contain metals, black circles–metalloids. Grey circles show neutral elements (noble gases and elements yielding amphoteric oxides)

It is hard to conceive the existence of any chemical elements arranged before the first square occupied by hydrogen because the proton and neutron, which form the nucleus of hydrogen, are the fundamental bricks of which the nuclei of all the other elements are built; hydrogen, no doubt, rightly stands at the head of Mendeleyev's Periodic Table. The question about the end of the table is much more complicated. The last place had long been occupied by uranium.

However, transuranium elements have been obtained in some experiments. Consequently, uranium does not terminate Mendeleyev's table. Nine more boxes have been occupied so far beyond uranium; these elements are: neptunium (No. 93), plutonium (No. 94), americium (No. 95), curium (No. 96), berkelium (No. 97), californium (No. 98), einsteinium (No. 99), fermium (No. 100) and mendelevium (No. 101).

As the figures at the top of each box show, each box is numbered. The numbers run one after another from one on. They are called the atomic numbers of chemical elements; they are related to the number of electric particles contained in the elements and are, therefore, very important and inalienable properties of each box, each element.

For example, atomic number 30 in the square occupied by zinc with an atomic weight of 65.38 is, on the one hand, the ordinal number of the square and shows, on the other hand, that the atom of zinc consists of a nucleus with 30 electric particles, called electrons, revolving around it.



Chemists made many vain attempts to find elements No. 43, No. 61, No. 85 and 87 in nature; they analyzed various minerals and salts and tried to discover some as yet unknown lines in their spectra. They made many mistakes, published bombastic articles about discoveries of elements, but these four elements have not been found either on the stars or on earth. It has now been possible, however, to prepare them artificially.

One of them, No. 43, is supposed to have properties similar to those of manganese. D. Mendeleyev named it ekamanganese.

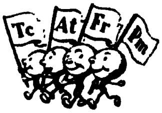
This element has now been synthesized and named technetium.

The second element is located below iodine and is designated by No. 85. It is supposed to have some fabulous properties and be even more volatile than iodine. D. Mendeleyev gave it the name of ekaiodine. It has also been synthesized and given the name of astatine.

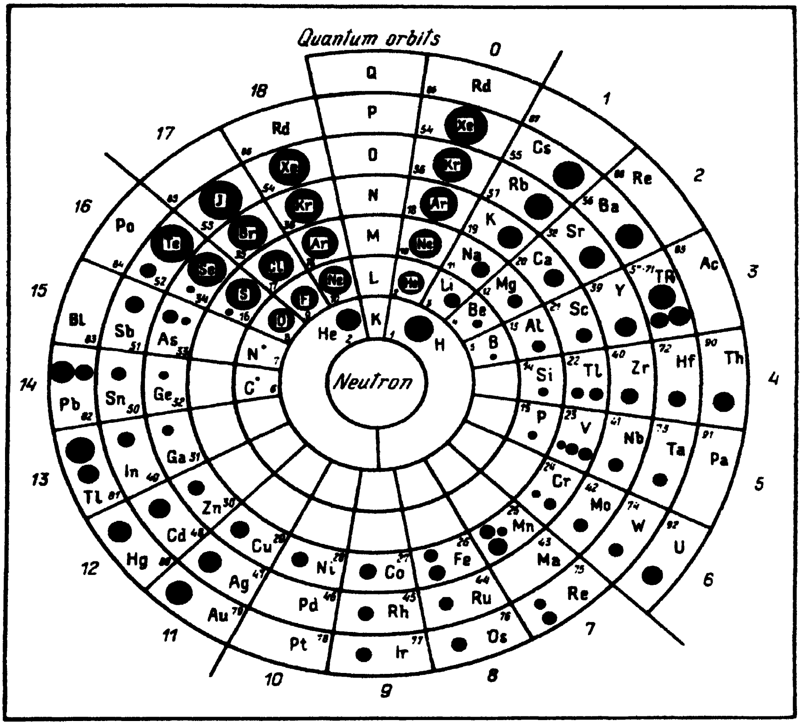
The third element, which had also been mysterious for a long time, is shown in our table under No. 87. It was predicted by Mendeleyev who named it ekacesium. It has been synthesized and named francium.

Finally, the fourth element, which has not been found either on the stars or on earth, is No. 61. It is one of the rare-earth metals. It has been synthesized and is now known as promethium.

Today the table of elements is much more complete than it was at the time D. Mendeleyev had to make out the complicated picture of nature and draw up his first draft of the table.

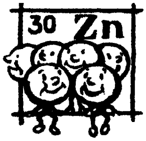


As we have already mentioned, each box with a definite number is occupied by one chemical element. Physicists have demonstrated, however, that it is really a much more complicated affair. Thus, according to the chemical properties, box No. 17 contains only one atom of the gas known as chlorine with a small nucleus and seventeen



D. Mendeleyev's periodic system of elements in the form of circles-spirals. The diameters of the little circles represent the sizes of the atoms and ions. (Drawn by Y. Bilibin in 1945)

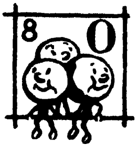
electrons which, like planets, surround it on all sides. Meantime, physicists indicate that there are two chlorines: one heavier, and the other—lighter. But since their proportion is equal everywhere their mean weight is always 35.46.



And here is another example. The familiar box No. 30 is occupied by zinc. But here, too, physicists point out there are different zincs, some heavier, some lighter, six different kinds in all. It, thus, turns out that though each box contains one chemical element with definite natural properties there may be several kinds or "isotopes" of this element. In some cases there is only one, in others there are even ten.

Naturally, the geochemists became extremely interested in this phenomenon. Why should all these isotopes be encountered in very definite amounts and why are there not more of the heavy element in some places and of the light element in other places? Chemists went to work checking on this fact. For analysis they took salts of different origin: common salt from the sea and from various lakes, rock-salt and salt from Central Africa; from each kind of salt they isolated the chlorine and unexpectedly obtained the same numbers for the atomic weight. They even took chlorine from the rocks that had fallen from the sky, but the composition of chlorine proved absolutely the same. And what we call atomic weight remained invariable, no matter where the element came from.

But the triumph of the chemists did not last long. Other investigators tried to separate these heavy and light isotopes of the atom in the laboratory. After complicated and lengthy distillation of chlorine gas they managed to obtain one gas composed of lighter atoms of chlorine and another made up of heavier atoms. Both these chlorines are chemically absolutely the same, but their weights differ.

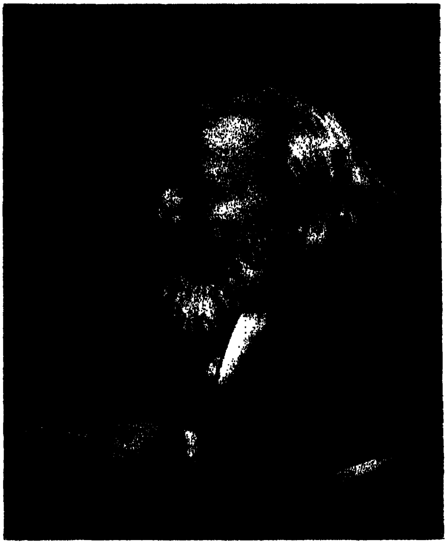


This discovery of isotopes of each element has rendered Mendeleyev's table more complicated. It seemed so simple before: 92 boxes with one chemical element in each. The number denoted how many electrons there were around the nucleus. Everything was so simple, so clear and so certain! And suddenly it had all turned out wrong!

Instead of one oxygen there are THREE of them and their weights are exactly 15, 16 and 18. But the most remarkable thing is that hydrogen also has THREE kinds of atoms, one with the weight of 1, the second with the weight of 2, and the third with the weight of 3. The second kind has been given a special name deuterium.

Chemically it is like ordinary hydrogen, but it has twice the weight of the usual hydrogen. At large plants where water is decomposed by means of electricity it has been possible to obtain pure deuterium and from the latter special water which contains heavy hydrogen instead of the light variety. It appears that heavy water possesses specific properties: it destroys life (very strongly affects living cells). In a word, it "behaves" in a very specific manner.

Following this achievement of the chemists the geochemists took up the same problem in relation to natural bodies. They thought that since it was possible to divide the atoms of hydrogen into various kinds in the retort nature was probably doing the same. Only in nature all chemical processes are very restless and the natural conditions of the molten magmas in the earth's interior or on its surface change so often that we can hardly expect the accumulation of pure isotopes which we have been able to obtain at factories and in research institutes. As a matter of fact it has turned out that the water of the seas and oceans contains a little more heavy water than do rivers and the rain. Certain minerals contain even more heavy water. A whole new world, formerly inaccessible to the mineralogist and geochemist, opened up before us.

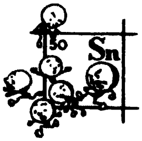


Portrait of D. Mendeleyev painted by his wife A. Mendeleyeva

The difference between these compounds is so negligible in nature that it requires the subtlest methods of chemical and physical analysis to discover it.

The millionths and even thousandths of a gram and centimetre are imperceptible to a mineralogist and geochemist when he studies the stones, the waters and the earths of surrounding nature. We may even forget that there are three oxygens, six zincs and two potassiums since the differences between them are so negligible and, frankly speaking, our methods of investigation are still so crude.

Only the chemists and physicists have learned to divide the elements into different isotopes by their precise investigations and there can be no doubt that when they master all of our nature by their most accurate methods they will discover the



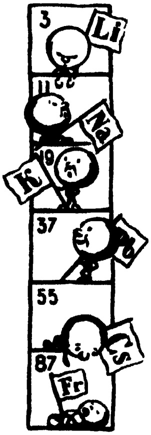
greatest laws of geochemistry of which we cannot even dream as yet.

Meanwhile you and I may forget about isotopes. As far as we are concerned each box in Mendeleyev's Periodic Table contains only one definite and invariable chemical element. For us, box No. 50 contains only one tin which is always and everywhere the same and which yields the same chemical reactions all over, is encountered in nature in the same crystals and has an atomic weight of 118.7 wherever it may be found.

Mendeleyev's Periodic Table is none the worse for this greatest discovery of isotopes; it has only become more complicated in its minutest details while remaining essentially as clear, simple and distinct a picture of nature as it was painted for us by Mendeleyev who foresaw its tremendous importance.

Let us go deeper into this table and see of what significance it is for the investigators of nature, the mineralogists and the geochemists.

Let us first take a look at each column of boxes from top to bottom.



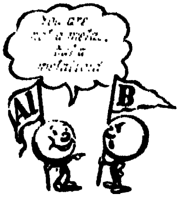
Here is the first column—lithium, sodium, potassium, rubidium, cesium and francium. These are all metals and we call them the alkali metals. In nature they occur together except artificially obtained francium. We know their compounds well: for sodium—common salt which you use with your food, and for potassium—saltpetre with which fireworks are made.

Then come very rare alkali metals which are now used in intricate electric appliances. But whatever the differences among all these elements they are very much alike chemically.

And here is the second vertical column in which we find the alkaline-earth metals from beryllium, the lightest, to the famous radium. These also resemble each other forming, as it were, one family.

Then comes the third column with boron, aluminium, scandium, yttrium, a box with fifteen rare-earth elements and, finally, actinium. Only the first two elements—boron and aluminium– which play an important part in nature are well known to us from everyday life. The first of these forms part of boric acid and borax which is used in soldering. Aluminium is a constituent of nepheline, feldspar, corundum and bauxite, while in its pure form we can see it in metal wares, pots and pans. This is a rather complex group.

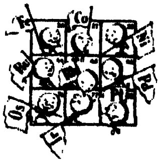
Aluminium may be considered a real metal, but boron is more like a non-metal because it forms salts (such as borax) with typical metals.


You are not a metal, but a metalloid
Al
B

We go on to the fourth column containing carbon, silicon, titanium, zirconium, hafnium and, finally, thorium. The first two are among the most important chemical elements in nature; carbon forms the entire mass of organic nature and is a constituent of all limestones, while silicon is an element about which you will read a special chapter.

We now come to the fifth, sixth and seventh columns. In these columns we have only special metals which are very highly valued in the metallurgy of iron and which are added to steel to improve its qualities.

And here is the remarkable middle of Mendeleyev's Periodic Table consisting of the eighth, ninth and tenth columns. The most curious feature of this part of the table is that the neighbouring metals are very much alike. Iron, cobalt and nickel greatly resemble each other and in nature are always encountered together; they are also hard to separate in chemical analysis. Ruthenium, rhodium and palladium (the light platinum metals), as well as osmium, iridium and platinum (the heavy platinum metals) resemble each other no less.



The centre of the table is followed by four vertical columns occupied by so-called heavy metals. These include copper, zinc, tin and lead which are familiar to us from our everyday experience.

Now comes column fifteen. It begins with the gas known as nitrogen. This is followed by volatile phosphorus and arsenic, semi-metallic antimony and, finally, by the rather typical metal, bismuth. This column marks, as it were, a sharp transition to the next part of Mendeleyev's Periodic Table where we shall no longer encounter any metals with metallic lustre and other familiar properties. There we find substances which chemists have named non-metals and which are gaseous, liquid or solid.

The sixteenth column contains oxygen, sulphur, selenium, tellurium and the mysterious polonium; this is followed by the seventeenth column of volatile substances, first gases—hydrogen, fluorine and chlorine, then liquid—bromine, and, finally, solid but also volatile crystals of iodine. Chemists have given this group of elements (except hydrogen) the name of halogens because they form salts with alkalis. This is denoted by the meaning of the Greek word: halogen means salt-producing. And here is the last column, the eighteenth, in which we find the rare or noble gases. These do not combine with anything but impregnate the entire earth, all minerals, everything that surrounds us in nature. They begin with light helium, the gas of the sun, and end with the remarkable gas called radon whose atoms live only a few days.

I live only 4 or 5 days
Rn

MENDELEYEV'S PERIODIC SYSTEM OF ELEMENTS IN GEOCHEMISTRY

How are the chemical elements distributed in the earth and all through nature? This has long been a question of great importance to man.

This question has always come to the fore spontaneously, arising from the needs of day-to-day life. Primitive man needed materials for his work-tools and for hunting weapons and shaped them from hard flint or from similarly hard, but stronger, nephrite. It is clear that the search for minerals began many thousands of years before our time when primitive man started paying attention to sparklets of gold in river sands and to the beauty or weight of different stones that attracted him.

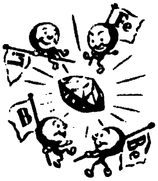
In this way man first found out about, and then learned to extract and process copper, tin, gold and, finally, iron. He gradually accumulated data and experience. The regions where man was to search for copper and cobalt minerals to manufacture blue dyes, and later to find iron for brown ochre, clay for statuettes and turquoise for the sacred scarabs were already known in ancient Egypt.

Little by little man learned the simple natural laws. It turned out that some metals were often encountered together, as, for example, tin, copper and zinc; in its time this suggested to man the idea of alloying them and producing bronze. Gold and precious stones were found together in other places, clay and feldspars, from which porcelain and faience can be made, in still other places.

Man has, thus, gradually discovered the fundamental laws of geochemistry. And the alchemists, who in the Middle Ages tried to produce gold and the philosopher's stone in the mysterious quiet of their laboratories, also contributed a good deal to the accumulation of natural facts.

Already the alchemists knew well that certain metals have an affinity for each other and are encountered together: thus sparkling crystals of galena are always accompanied in the earth by zinc-blende, silver follows gold, while copper is often found together with arsenic.

When mining developed in Europe the geochemical regularities became clearer and more distinct. The fundamental principles of the new science of geochemistry were coming into being in the deep mines of Saxony, Sweden and the Carpathians; it was ascertained what substances were found in nature together and under what conditions, and what laws forced some elements to accumulate in certain parts of the earth and disperse in others.



These were the most urgent questions in mining, which required the ability to find places where the industrially important metals—iron, gold, etc.—accumulated in large quantities.

Today we know that the common occurrence of elements and their behaviour are subject to very definite laws and that these laws help in prospecting for minerals.

We know very well from our own daily practice that such natural elements as nitrogen, oxygen and the rare, noble gases are found principally in the atmosphere. We also know that in salt-lakes or in salt mines the salts of chlorine, bromine and iodine are found together in combination with the metals—potassium, sodium, magnesium and calcium.

In granites, these light crystalline rocks which have resulted from the cooling of molten magmas, we find their own definite chemical elements. They are connected with precious stones which contain atoms of boron, beryllium, lithium and fluorine. They also include accumulations of important and rare metals—tungsten, niobium and tantalum.

Unlike the granites, in the heavy basalt rocks which have streamed out of the earth's interior we find together the minerals of chromium, nickel, copper, iron and platinum. In the complexly ramified systems of lodes branching out of immense underground lakes of molten magma which rises to the earth's surface the prospector finds zinc and lead, gold and silver, arsenic and mercury.

The more our science develops the clearer and more certain become the laws which were long incomprehensible.

Meanwhile, let us take a look at Mendeleyev's Periodic Table. Don't you think it is the same compass for us searchers for stones and metals as it is for the chemists?

The centre of Mendeleyev's Periodic Table is occupied by nine metals: iron, cobalt, nickel and six metals of the platinum group. We know their deposits lie deep in the entrails of the earth. If tall mountain ranges are eroded over millions of years almost to the level of plains, as is the case in the Urals, these green Plutonic rocks, the bearers of iron and platinum, are laid bare.

You see that these elements are not only the foundation of our mountain ranges, but that they also occupy the central place in Mendeleyev's Periodic Table.

Let us turn to the metals which we call heavy and which take up considerable space to the right of nickel and platinum. These are copper and zinc, silver and gold, lead and bismuth, mercury and arsenic. Have we not just said these metals were always encountered together? Miners look for them in lodes which cut through the earth's crust.

Now let us go left of the centre of the table where we observe a similar field. These are the familiar metals which form the precious stones, the compounds of beryllium and lithium; they are the rare and ultra-rare elements which accumulate in the outermost extrusions of granite massifs, in large granite pegmatites.

Let us go farther left and right in our table. We must not forget, however, that its long rows close in in a common spiral and that the extreme left and right groups are contiguous. Here we see the very familiar elements of salt deposits: salt-lakes, seas and oceans, and extensive accumulations of rock-salt. These are the elements that form the salts of chlorine, bromine, iodine, sodium, potassium and calcium.

And now look carefully at the top right-hand corner of the table; here you will find the chief elements of the atmosphere— nitrogen, oxygen, hydrogen, helium and other noble gases; at the top left-hand corner you will see lithium, beryllium and boron. Don't they remind you of the volatile parts of the granite massifs where the beautiful precious stones— the pink and green tourmalines, the bright-green emeralds and violet kunzites are formed? As you see, Mendeleyev's Periodic Table itself suggests the groups of elements encountered in nature and really and truly serves as a compass for the search of minerals.

Cliffs on the banks of the Chusovaya River (Sverdlovsk Region)

In order to confirm the *regularities mentioned* by an example let us recall the chief minerals found in the Urals.

The Urals appears before us as an enormous Mendeleyev's Periodic Table spreading across the rocks. The axis of the range and of the table passes through the heavy green rocks of platinum deposits. Its extreme groups are in the salt zone of famous Solikamsk and in the regions of the Emba.

Is it not a marvellous confirmation of the profoundest and most abstract ideas? I believe you have already guessed that in Mendeleyev's table the elements are not arranged fortuitously but according to the similarities of their properties. And the greater the similarities between the elements the closer to each other they are found in the Periodic Table.

It is the same in nature. The signs showing various minerals on our geological maps have not been put there by mere accident, as it is no accident that osmium, iridium and platinum or antimony and arsenic are encountered in nature together.

The same laws of similarity, of chemical affinity of the atoms determine the behaviour of the elements in the earth's entrails. The Periodic Table is really the most important instrument with the aid of which man discovers the resources of the earth's interior, finds useful metals and employs them in developing his economy and industry.

Let us recall the distant past of the Urals. Heavy molten magmas consisting of dark, black and green Plutonic rocks rich in magnesium and iron rose from the interior of the earth. They received an admixture of chromium, titanium, cobalt and nickel ores; to these were added the metals of the platinum group—ruthenium, rhodium, palladium, osmium, iridium and platinum.

Thus began the first stage in the history of the Urals, the deeply imbedded chain of dunite and serpentine rocks that form the central frame of the Urals Range which stretches to the Arctic islands in the North and is buried under the feather-grass steppes of Kazakhstan in the South. In Mendeleyev's Periodic Table it is the central part.

In the process of separation of melts the lighter volatile substances are evolved, and in the complex change of rocks which form the present-day Urals light-coloured granites crystallized out in the interior at the end of its volcanic activity. It is the grey granite so familiar to all who live in the Urals, especially along its eastern slopes. White veins of pure quartz pierce the granite and thick pegmatite veins branch into its external sections and penetrate into the lateral rocks. These processes lead to the accumulation of the volatile elements boron, fluorine, lithium and beryllium and the rare earths and to the formation of the precious stones and rare-metal ores of the Urals.

In Mendeleyev's periodic system it is the left field of the table.

But hot solutions rose to the surface both at the same time and later. They bore the low-melting, mobile and highly soluble compounds of zinc, lead, copper, antimony and arsenic, and with them carried silver and gold.

These ore deposits run in a long chain along the eastern slopes of the Urals, now forming large concentrations—lenses, now branching lodes and clusters of lodes.

In Mendeleyev's Periodic Table it is the right field of ore elements.

But then the volcanic activity came to an end and the pressures, which raised the Urals, shifted its ridges from East to West and opened here and there an outlet for volcanic rock and for the hot waters of the veins, ceased.

Then a lengthy period of destruction began. For hundreds of millions of years the Urals Mountains eroded, their rocks being weathered away. All that was hard to dissolve remained, the rest was dissolved and carried away by water to the seas and lakes. The Great Permian Sea which washed the western slope of the Urals accumulated these substances. The sea began drying out; bays, lakes and firths were detached from it and the salts settled to the bottom.

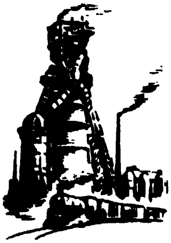
It was, thus, that the salts of sodium, potassium, magnesium, chlorine, bromine, boron and rubidium accumulated.

In Mendeleyev's Periodic Table they occupy the upper and the left-hand boxes.

And only what did not yield to the chemical action of water now remains where once there were the mountain peaks of the Urals.

A crust of disintegrated rock grew for scores of millions of years in the tropical climate of the Mesozoic era. Accumulating in this crust iron, nickel, chromium and cobalt formed the rich deposits of brown hematite which laid the foundation for the nickel industry in the South Urals.

Quartz deposits accumulated in the regions of granite disintegration. Gold, tungsten and precious stones were retained and concentrated in these deposits and in sands.

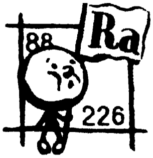


Thus, the Urals gradually died covering up with soil, and only now and then waters rushed in from the East eroding its already overgrown hills and depositing manganese and iron ores along the shores.

We find Mendeleyev's Periodic Table hidden under the taiga of the polar Urals and under the feather-grass steppes of Kazakhstan. Soviet people are now discovering various elements of this table and are utilizing them for industrial purposes.

THE ATOM DISINTEGRATES. URANIUM AND RADIUM

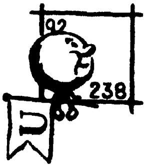
The preceding chapters told us that the atom, which in Greek means "indivisible," forms the basis of the science of geochemistry. All of the surrounding nature is composed of a combination of 101 varieties of atoms which correspond to 101 different elements.



But what is this minutest "indivisible" particle of matter? Is it really "indivisible"? Do the 101 varieties of atoms actually exist independently of each other without displaying any unity of structure?

The idea of the atom as a materially indivisible globule formed the foundation of chemistry and physics. The "indivisible" atom quite explained the physical and chemical properties of matter, and for this reason chemists and physicists were not particularly anxious to discover the complex structure of the atom though they suspected it.

And only when the famous French physicist Becquerel discovered in 1896 the phenomenon of some invisible radiation by uranium unknown until then and the Curies found the new element known as radium, in which this phenomenon was much more pronounced, it became clear that the atom had a very complex structure. Now, after the brilliant work of Marie Curie-Sklodowska, the Curie-Joliots, Rutherford, Rozhdestvensky, Bohr et al, the picture of the atom's structure is sufficiently clear. We know not only the simplest particles of which the atom is composed, but also their sizes, weights, mutual location and the forces that bind them.



We have already said that the atom of each chemical element despite its negligible size (it has a diameter of 0.00000001 centimetre) represents a very complex structure built like our solar system.

Marie Curie-Sklodowska in her Paris laboratory

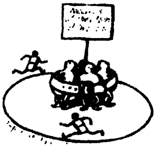
The atom is composed of a nucleus its diameter is 0.00001 that of the atom and corresponds to about 1 ^{12} cm in which the bulk of the atom is concentrated.

The nucleus of the atom carries a positive electric charge. The number of the positive particles in the nucleus increases with the transition from the atoms of the light chemical elements to the heavy ones and corresponds numerically to the number of the box the element occupies in the Periodic Table.

Electrons, each carrying a negative charge, revolve around the nucleus at various distances from it. The number of electrons equals that of the positive charges on the nucleus, so that the atom as a whole is an electrically neutral structure.

The nuclei of the atoms of all chemical elements are built of two simplest particles a proton, or hydrogen atom nucleus, and a neutron. The proton has a mass nearly equal to that of the hydrogen atom and carries one positive charge. The neutron is a material particle with a mass similar to that of the proton but without any electric charge.

The protons and neutrons in the nuclei of atoms cohere so firmly that in all chemical reactions the nuclei of the atoms are perfectly stable and remain unchanged.



If we gradually pass from the lighter to the heavier chemical elements in Mendeleyev's periodic system we will find that the nuclei of the atoms of the light elements are composed of an approximately equal number of protons and neutrons this is easy to see from the fact that the atomic weight of the elements in the beginning of the Periodic Table is either numerically equal or close to the doubled atomic number of the elements.

With a transition to the heavier chemical elements the number of neutrons in the nuclei of the atoms begins to exceed that of the protons. Finally, the number of neutrons considerably exceeds that of the protons and the nuclei of the atoms become unstable. Beginning with the 81st atomic number we encounter unstable, as well as stable, varieties of atoms of chemical elements. The nuclei of the atoms of the unstable elements spontaneously disintegrate liberating large amounts of energy and change to atoms of other chemical elements.

They are pulling us over!

From atomic number 86 on all nuclei of atoms of chemical elements represent unstable structures and the corresponding elements are radioactive.

Radioactivity is a property of the atom to disintegrate spontaneously changing to atoms of other elements with a liberation of large amounts of energy in the form of different radiations. The latter have been divided into three groups.

The first is the alpha rays or a stream of fast travelling material particles with a double positive electric charge: each alpha particle has a mass four times that of the hydrogen atom and is actually a nucleus of the helium atom.

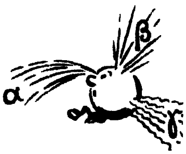
The second is the beta rays or a stream of electrons travelling at an enormous rate. Each electron carries one negative charge, the smallest of the existing charges, and has a mass 1/1.840 that of the hydrogen atom.

The third group is formed by gamma rays which represent a radiation resembling X-rays, but with a shorter wave-length.

If we put about a gram of a radium salt into a small glass tube, solder this tube and watch it, we shall be able to observe all the principal phenomena that attend radioactive disintegration.

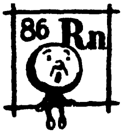
In the first place, if we use an instrument sensitive enough to measure slight differences in temperature, we shall easily discover that the temperature of the tube containing radium salt is somewhat higher than that of the environment.

You get the impression there is an efficient heating device hidden in the radium salt. On the basis of this observation we can draw an important conclusion that radioactive disintegration or the process of break-up of the atomic nuclei is attended by a continuous production of large amounts of energy. Experience shows that in "breaking up" one gram of radium produces 140 small calories of heat per hour



while in changing completely to lead (which takes about 20,000 years) it will produce 2.9 million large calories of heat, i.e., as much as is produced by the burning of half a ton of coal.

Now let us take a small pump and pump the air out of the tube containing radium into another tube from which the air was pumped out beforehand. Let us solder this new tube. We will soon find that in the dark this tube emits a greenish-bluish light just like the tube with the radium salt.



This secondary radioactivity is due to the appearance of a new radioactive substance born of radium. This substance is a gas. It has been named radon (Rn).

The amount of radon in the tube increases for a period of forty days after which it becomes constant because the rate of disintegration of radon then equals the rate of its emission. We can observe radioactivity by holding the tubes up to a charged electroscope. Radioactive radiation ionizes the air making it a conductor of electricity and the electroscope runs down.

If we watch the effect of the tube containing radon on a charged electroscope day after day we shall easily observe that in the course of time this effect weakens. Within 3.8 days the effect will be half lost, and if the tube is brought close to a charged electroscope 40 days later it will fail to produce any effect. But if we pass an electric discharge through one of these "mature" tubes and observe the luminescence of this gas produced by the discharge in a spectroscope we shall discover the appearance of the spectrum of a new gas helium. Finally, if we thoroughly remove the radium salt from the tube after keeping it in the latter for many years and then by sensitive methods of analysis test the surface of its inner walls for the presence of foreign chemical elements we will be able to find minutest traces of lead in the empty tube.

In one year the disintegration of the atoms of one gram of metallic radium produces $4.00 \cdot 10^{-4}$ grams of lead with a mass number of 206 and 172 cubic millimetres of gaseous helium.

Thus, radioactive disintegration of radium results in one new radioactive element after another with the final formation of non-radioactive lead. At this stage transformation ceases. Radium is itself only an intermediate link in a long chain of products of uranium transformation.

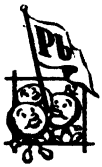
The series of elements produced as a result of disintegration of radioactive elements is known as the radioactive series.

All the nuclei of each radioactive element are unstable and are equally probable to disintegrate in a given period of time. Thus, a sufficiently large sample of radioactive substance containing many millions of atoms always disintegrates at the same constant rate regardless of any chemical or physical influences.

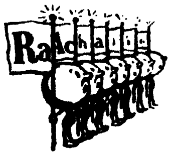
It has been demonstrated that no external physical influences produce any effect on the decay of a radioactive substance, be it a temperature of liquid helium, which is close to absolute zero, or temperatures of several thousand degrees, pressures of several thousand atmospheres or high-voltage electric discharges.

The rate at which a radioactive substance disintegrates, or is transformed, is usually expressed by the half-life period *T* or the time required for half the initially present atoms of the substance to disintegrate. This value is, apparently, characteristic of and constant for each variety of unstable atoms, i.e., for each given radioactive element.

The half-life periods of radioactive elements vary very widely—from a fraction of a second for the most unstable atomic nuclei to thousands of millions of years for the slightly unstable elements which include, for example, uranium and thorium. Like its radioactive "parent" the "daughter" nucleus is frequently itself an unstable radioactive substance and decays further until a stable nucleus is formed after several successive generations of nuclei.



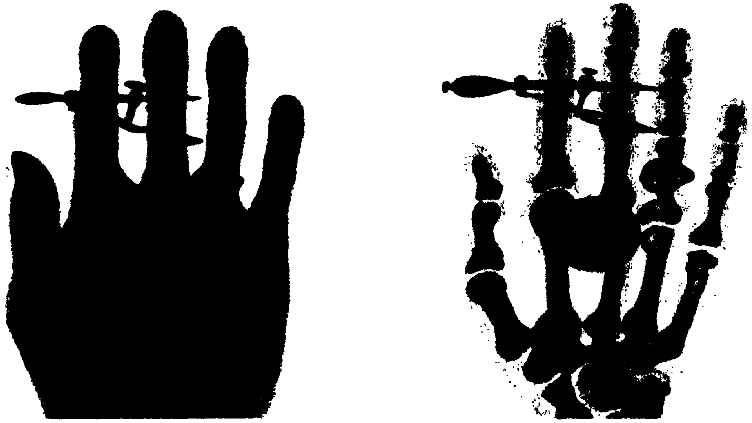
Three such natural radioactive series or families are known today: the uranium-radium series beginning with the isotope of uranium with a mass number of 238, the uranium-actinium series beginning with another isotope of uranium with a mass of 235 and the thorium series. The nuclei of the atoms of lead isotopes with mass numbers of 206, 207 and 208 respectively are the stable and no longer disintegrating end-products of each of these series formed after ten to twelve successive transformations. In addition to lead the alpha particles, which have lost their kinetic energy and charge and have become atoms of helium, are stable products of transformations in each of the above radioactive series.



During the incessant radioactive disintegration of the uranium, thorium and radium atoms on earth heat is continuously produced.

If we calculate the amount of heat produced by all the aforesaid elements during their decay we shall find that, without the least suspecting it, we have long been using this heat because the latter noticeably heats our earth.

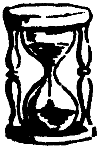
It happens very similarly that the helium gas used in filling dirigibles and barrage balloons is formed by the radioactive decay of the atoms of uranium, thorium and radium found in the earth. It has been computed that enormous amounts of helium gas constituting many hundreds of millions of cubic metres have thus formed in the earth since its existence.


Two pictures of a human hand: left in the rays of radium right taken with the aid of X rays. Metals are not transparent

The continuous disintegration of the atoms of uranium, thorium and radium contained in the earth is of interest to us not only as a source of constant heat and of formation of industrial reserves of chemical elements, but also as a natural timepiece by which we can tell the time that has elapsed since the formation of any particular rock and of the very earth as a solid body.

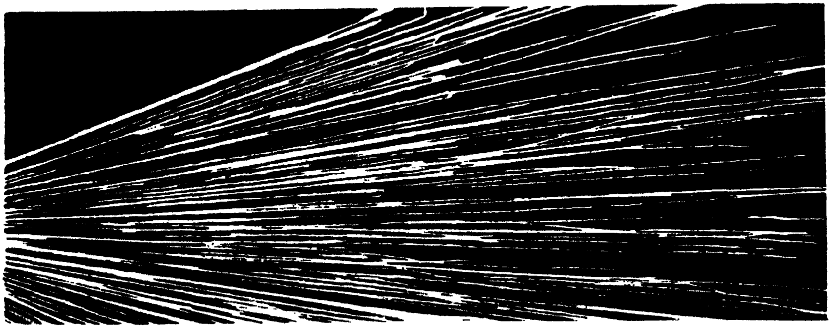
But how can we use the atoms of uranium, thorium and radium as a timepiece for telling geological time? Here is how. We see that the rate at which disintegration of radioactive atoms takes place is not subject to any chemical or physical influences and remains strictly constant. On the other hand, during radioactive decay stable and no longer changing atoms of the elements helium and lead are formed and, as time wears on, their amounts will increase more and more.

Since we know the amount of helium and lead formed as a result of radioactive decay of the atoms of one gram of uranium or thorium in one year we determine the amount of uranium or thorium contained in a particular mineral and the amount of helium and lead in the same mineral, and by taking the ratio of helium to uranium and thorium, on the one hand, and the ratio of lead to uranium and thorium, on the other, we get the time in years that has passed since the moment this mineral was formed.



As a matter of fact, when the mineral was formed it contained only atoms of uranium and thorium and had no atoms of helium or lead; then through the disintegration of the atoms of uranium and thorium atoms of helium and lead began to appear and gradually to accumulate in the mineral.

A mineral containing atoms of uranium and thorium may be likened to a sand-glass, and you have probably all seen how it works. Let me remind you how it is made. It consists of two intercommunicating vessels one of which contains a certain amount of sand. As the sand-glass is put in operation it is fastened and the sand is allowed to pour slowly from the upper vessel into the lower by force of gravity.



Destruction of nitrogen nuclei under the action of alpha particles. Long-range protons are liberated

The amount of sand is usually put in the sand-glass with the idea that it empty into the lower vessel in a definite period of time, say, 10 or 15 minutes. In practice a sand-glass is used to measure constant periods of time though it could be used to measure any periods of time. For this we would either have to weigh the amount of sand or to mark off equal volumes in the vessels and measure the volumes of sand poured in. Since sand flows at a definite rate under the action of gravity *we can determine by volume the amount of sand pouring from the upper vessel into the lower per minute and tell the number of minutes* that have elapsed from the time we put the sand-glass in operation by the volume of sand we find in the lower vessel.

Something like this is happening to the mineral in which atoms of uranium and thorium are found. It resembles the upper vessel that contains a certain amount of sand, only the part of the sand grains is played by the atoms of uranium and thorium. They are also transformed into atoms of helium and lead at a definite rate and, as is the case with the sand-glass, the atoms of disintegration accumulate in direct proportion to the time that has elapsed since the existence of the radioactive mineral.

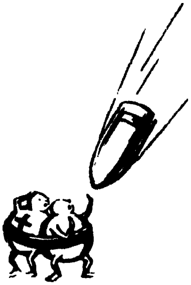
We determine the amount of remaining uranium by direct analysis and estimate the number of disintegrated atoms of uranium and thorium by the amount of helium and lead that have formed from them. These data make it possible to find the ratio of uranium to the amount of the lead and helium produced and, consequently, to estimate the time during which the decay took place. In this manner scientists have been able to determine that there are minerals on earth since the formation of which nearly two thousand million years have passed. Thus, we now know that our earth is a very old old-lady and that she is considerably older than two thousand million years.

To conclude this chapter I should like to tell you about one more phenomenon which was discovered very recently and which is probably destined to play an important part in the life of people. We have seen that beginning with atomic number 81 in Mendeleyev's periodic system the atoms of the heavy chemical elements have not only stable, but also unstable nuclei, the latter possessing the property of radioactivity. It also turns out that the nucleus of an atom becomes unstable if a certain definite proportion between the protons and neutrons is greatly disturbed. With the number of neutrons greatly exceeding that of the protons in the nucleus the latter becomes unstable.

As soon as scientists noticed this property of the nuclei of chemical elements they found a means of artificially changing the proportion between the protons and neutrons in the nuclei and, thus, to transform the stable varieties of atomic nuclei into unstable ones and to make chemical elements artificially radioactive at their will. How can this be done?

To do this we have to find some sort of projectile not larger than the nucleus of the atom, impart a great deal of energy to it and fire it into the nucleus of the atom.

The alpha particles emitted by radioactive substances are just the projectiles of atomic size with a very great amount of energy. They were the first to be employed by scientists for the purpose of artificially breaking up the nucleus of the atom. Ernest Rutherford, famous British physicist, was the first to succeed with it; while acting on the nuclei of nitrogen atoms with alpha rays in 1919, he discovered that these atoms emitted protons.

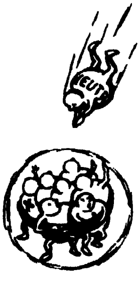


Fifteen years later, in 1934, the young French scientists, Irène Curie-Joliot and Frédéric Joliot by acting on aluminium with the alpha particles of polonium discovered that under the action of the alpha rays aluminium not only emanated rays containing neutrons, but retained its radioactive properties and continued to emit beta rays for some time after the end of irradiation by alpha particles.

By chemical analysis the Joliot-Curies ascertained that it was not the aluminium itself that became artificially radioactive but the phosphorus atoms formed from the atoms of aluminium under the action of the alpha particles.

Thus, the first artificially radioactive elements were obtained and artificial radioactivity was discovered. After trying various methods to obtain artificially radioactive elements scientists soon began acting on the nuclei of chemical elements by neutrons instead of alpha particles since the former penetrate into the atomic nuclei more easily than the latter which have a positive charge and are, therefore, repelled by the nucleus as they approach the atom.

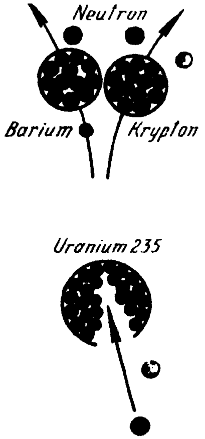
These repelling forces are so great in the nuclei of the atoms of the heavy chemical elements that the energy of alpha particles does not suffice to overcome them and the alpha particles cannot reach the nucleus of the atom. Since neutrons do not carry any electric charge they are not repelled by the nuclei and easily penetrate into them. As a matter of fact, it has been possible to obtain artificially radioactive unstable varieties of atomic nuclei for all the chemical elements by acting on these elements with neutrons.



In 1939 it was discovered that when uranium, the heaviest chemical element, was acted upon by neutrons of low energy, the atoms of uranium suffered a new, formerly unknown, type of disintegration in which the nucleus of the atom split up into two approximately equal halves. These halves are themselves unstable varieties of the atomic nuclei of familiar chemical elements found in the middle of Mendeleyev's Periodic Table.

One year later. in 1940, K. Petrzhak and G. Flerov, young Soviet physicists, discovered that this new type of disintegration or new type of radioactivity of uranium, also occurred in nature, but that it was encountered much more rarely than the usual disintegration of uranium.

If it takes half of all the atoms contained by uranium 4,500 million years to break up in ordinary radioactive decay, disintegration by division of the atoms in halves takes 44×10^{15} years. Consequently, this second type of disintegration occurs ten million times as slowly, but is accompanied by a much greater liberation of energy than the usual radioactive disintegration.



Destruction of a uranium atom by a slow neutron

As scientists demonstrated in 1946, certain stable nuclei of elements are formed in the new type of radioactivity of uranium as well; these continuously accumulate in nature along with the formation of unstable and further disintegrating nuclei.

Whereas the usual radioactive disintegration is attended by a formation and gradual accumulation of the atoms of helium the new type of radioactivity of uranium results in the formation and gradual concentration of the atoms of xenon or krypton.

By bombarding the isotopes of uranium it has been possible to obtain a number of new transuranium elements—neptunium with the atomic number of 93, plutonium—94, americium—95, curium—96, berkelium—97, californium—98, einsteinium—99, fermium—100 and mendelevium—101; they have all found their places in Mendeleyev's Periodic Table.

The most interesting, though, is the fact that by this new type of disintegration it has become possible to direct and accelerate or slow it down at will. If this process be greatly accelerated and the atoms contained in one kilogram of uranium be made to break up in this manner at once the energy and heat liberated as a result will equal that produced by the combustion of 2,000 tons of coal and a tremendous explosion will occur.

After the explosion the fragments themselves will seek new forms of equilibrium until they liberate the surplus energy and change to more stable and slowly disintegrating atoms of different metals.

The remarkable part of this discovery is that human engineering not only produces these stormy reactions which liberate tremendous energy, but can also influence, retard or accelerate them and replace the stormy explosions by a slower and quieter liberation of powerful energy over a period of thousands of years. And the brilliant thought about nuclear energy which was only arising at the end of the 90's in the mind of Pierre Curie, who jointly with his wife discovered radium, the thought that only few scientists dared express on the threshold of the new century, is now becoming reality.

When in 1903 the scientists painted a picture of a happy future of humanity possessing endless reserves of the energy it needed, this idea seemed only a beautiful fantasy and did not find confirmation either in real facts of nature or in the achievements of the engineering of the time. And now this dream is coming true.

Small wonder that uranium has lately become

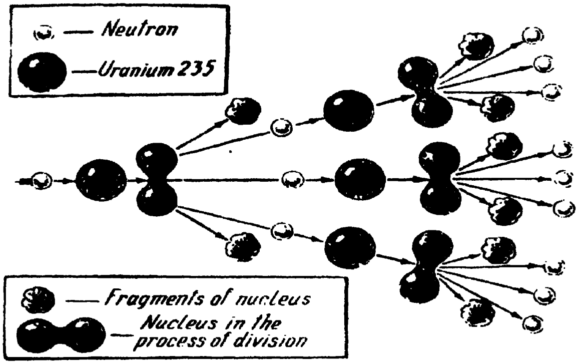
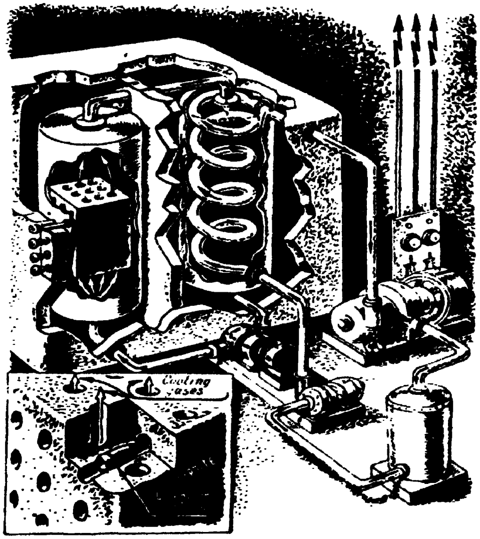


Diagram of self-sustained chain reaction in the nuclei of uranium atoms 235 the object of exceptional attention in all countries. Formerly it was only a waste product of radium production. The radium concerns in Belgium, Canada, the United States and other countries tried to find application for this by-product at large radium plants. But they could find no real use for it: it was low-priced and was utilized in dyeing porcelain and tile and in the production of cheap green glass.

The situation has changed of late; having become the centre of attention it is now uranium and not radium that is being searched and prospected for.

Even if it still requires a lot of effort to master this problem, even if this power is more expensive in the beginning than the power we get from steam-boilers, grand opportunities for utilizing these practically eternal engines open up before humanity.



Uranium reactor. This is the name given to the device in which the chain nuclear reaction of uranium 235 takes place. It is an enormous tank filled with uranium and graphite, which decelerates the reaction. On the outside the reactor is surrounded by a substance which reflects neutrons

Man has a new form of energy more powerful than anything ever known before.

The scientists the world over are now doing their best to master this great new force as soon as possible.

It is a matter of regret that the warmongers are trying to utilize this energy primarily for destruction. But the forces that are capable of frustrating the plans of the handful of imperialists and of making this new power serve all of working humanity have already matured. In the Soviet Union atomic energy is already being used for the production of electric power.

When the time comes that atomic energy is a commonplace thing we shall have electric stations fitting in a suit-case, motors of several horse power the size of a pocket watch, jet propulsion with a reserve of energy lasting several years and planes capable of flying for months on end without refuelling.

The age of atomic energy, the age of unprecedented might of man is in the offing.

And in the light of the new ideas about the structure of the atom D. Mendeleyev's Periodic Law has retained its significance.

Moreover, it will serve as the same guiding star in cognizing the intra-atomic phenomena as it has served in learning the chemical relations between the atoms.

We are beginning a new age of uranium and atomic energy!
U

THE ATOM AND TIME

The world is more than 2,000,000 years old

It is hard to conceive a simpler and at the same time a more complex idea than *time*. An old Finnish proverb says: "There is nothing more remarkable, more complex and more invincible in the world than time." Aristotle, one of the greatest philosophers of the ancient world, wrote four centuries B.C. that amid the unknown in surrounding nature the most unknown was time because nobody knew what time was nor how to control it.

Even at the early stages of culture man wondered about the beginning of time, about the end of the world, about how surrounding nature was created, about the age of the earth, the planets and the stars and about how long the sun would shine in the sky.

According to ancient Persian legends the world has existed only 12,000 years.

The astrologers of Babylon who told fortunes by the stars believed the world was very old, that it was more than two million years old, while the Bible taught it was only six thousand years since the will of God had created the world in six days and six nights.

The greatest minds continued studying the problem of time for many thousands of years, and the ancient legends and fantasies of astrologers were gradually replaced by exact methods of estimating the age of our earth.

The astronomer Galileo was the first to attempt an estimate of the earth's age in 1615; he was followed by Lord Kelvin in 1862. The latter calculated the age of the earth on the basis of the theory of its cooling and arrived at a figure which appeared enormous at the time—forty million years.

Then geological methods came into use. In Switzerland, Britain, Sweden, Russia and America geologists began estimating the time our earth required to form the sedimentary rocks which are over one hundred kilometres thick.

It appears that rivers annually carry away at least 10 million tons of substance which they erode from the continents so that every 25,000 years our continents lose a layer of earth on the average one metre thick. Thus, by gradually studying the activity of water and glaciers, the sediments on the earth and in the oceans and the striated glacial clays geologists have come to the conclusion that 40 million years could not cover the history of the earth's crust. In 1899 the British geophysicist Joly estimated the age of our earth at 300 million years.

But these estimates did not satisfy either the physicists or the chemists or even the geologists themselves.

The destruction of the continents did not at all proceed as regularly as Joly believed. The periods of sedimentation were followed by stormy explosions of volcanoes, earthquakes and rises of mountain ranges. The sediments already accumulated were melted and eroded.

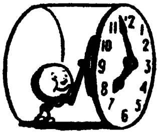
Joly's estimate did not satisfy the exact investigators who wanted to find a real timepiece to tell the time of the past, a reliable gauge to estimate the age of the earth's crust.

And then chemists and physicists came to take the place of the geologists. They, finally, found a timepiece, a perpetual and eternal timepiece. This timepiece was not made by a skilled workman, it has no springs to make it run and does not need winding. This timepiece is the disintegrating atom of radioactive elements.

We have already learned in the preceding essay that the whole world is filled with disintegrating atoms and that the atoms of uranium and thorium, radium and polonium, actinium and many dozens of other elements break up in the unnoticeable but great process. This disintegration proceeds at a constant rate and, as before stated, cannot be accelerated or slowed down either by high temperatures of thousands of degrees or by the lowest temperatures approximating absolute zero, or yet by enormous pressures. No usual means can alter this definite and invariable process of disintegration of certain atoms which takes place in nature.

True, modern engineering has managed to find powerful means by which it is able to destroy and create atoms. But there are no such conditions in nature and the invariable rate of disintegration of the heavy elements is maintained for millions and thousands of millions of years.

The atoms of uranium, radium and thorium break up and certain amounts of atoms of helium and stable, lifeless atoms of lead are simultaneously formed always and everywhere in the universe. These two natural elements—helium and lead—have created a new timepiece. And now, for the first time in human history, it has become possible to measure time by a real world standard of an eternal character.



What a striking picture which is at the same time so difficult of comprehension! Several hundred different atoms fill the universe with their complex electromagnetic systems. While radiating energy, they change by leaps from one form into another: some of the newly created systems are viable and are stubbornly preserved (the enormous length of the period of their transformations is, apparently, inaccessible to us); others exist thousands of millions of years slowly emitting energy and going through complex series of disintegration; still others live for years, days or hours; others yet exist seconds and even fractions of seconds.

Obeying the laws which govern the transformation of atomic systems the elements fill nature, but *time* regulates their quantitative dispersion, *time* distributes them through the universe and creates the complexity of life on our earth and in the universe.

Universal processes run slowly and eternally; the rapidly disintegrating heavy atoms die, others break up under the action of alpha particles, still other and stabler universal bricks are created, and non-radioactive elements, the end-products of disintegration, gradually accumulate.

It has already been established that elements stable against alpha rays prevail in the sun; 90 per cent of the earth's surface consists of elements with an even number of electrons or a number divisible by four, i. e., precisely the elements most stable against the destructive action of gamma rays and cosmic rays. The stablest of these, simply and densely built, form our inorganic world; the less stable (as potassium and rubidium) take part in the vital processes and by their disintegration help the organisms to fight for their lives. The rapidly disintegrating elements (radon and radium) destroy this life by destroying themselves. In some stellar systems the process of disintegration is only developing, as is the case in the rather mature system of our sun: in other systems—in stellar nebulae—it is only beginning; in still others—in the dark extinguished bodies—the fading processes of disintegration are now taking place infinitely slowly. *Time* determines the composition, nature and combination of elements in the course of cosmic history.

Our planet is about 3,000 million years old

Physicists and chemists have figured out that 1,000 grams of uranium will yield 13 grams of lead and 2 grams of helium in 100 million years.

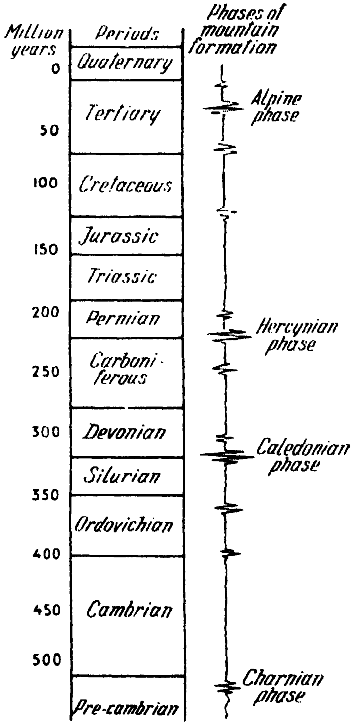
In 2,000 million years the amount of lead will already reach 225 grams, i.e., one quarter of the uranium will change to lead, and 35 grams of volatile helium will accumulate. But the process continues and in 4,000 million years there will be 400 grams of lead and 60 grams of helium with only half, 500 grams, of the primary uranium remaining.

Let us go on with our reasoning: let us take 100,000 million years rather than only 4,000 million: by that time most of the uranium will disintegrate and change to lead and helium. There will be hardly any uranium left on earth; heavy atoms of lead will be dispersed everywhere in nature instead and the atmosphere will be enriched by helium, the gas of the sun.

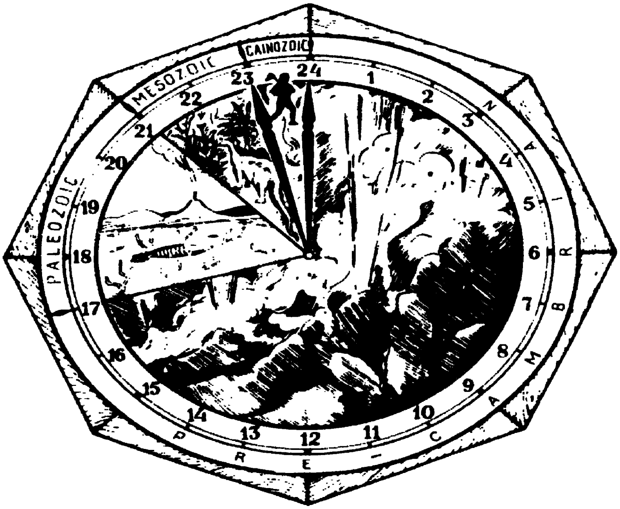
And so on the basis of these data geochemists and geophysicists have recently drawn up an absolute chronological scale of the geological evolution of the earth.

This new timepiece tells us that the age of our planet probably exceeds 3 to 4 thousand million years, i.e., 3 to 4 thousand million years must have elapsed since the moment in cosmic history when the planets of our solar system including the earth were formed.

AGE OF THE EARTH



More than 2,000 million years separate us from the appearance of the earth's hard crust, this second most important moment in the history of the earth, the beginning of its geological history. At least 1,000 million years has passed since the beginning of life. The famous Cambrian blue clay found in the environs of Leningrad began to be deposited about 500 million years ago.



"Timepiece" measuring the age of the earth. If we take the duration of the earth's history from the beginning of the most ancient archaic era to our days as 24 hours and correspondingly reduce the duration of all eras estimated by the radioactive process, our timepiece will show seventeen hours for the pre-Cambrian era, four hours for the Paleozoic era, two hours for the Mesozoic era and one hour for the Cainozoic era. Man appears only five minutes before midnight

During the first epoch, i.e., three-fourths of the entire geological history of the earth, molten masses repeatedly broke out of the interior to the surface and disturbed the calm of the first, still thin, but hard shell of the earth. The molten masses poured out on to its surface, impregnated it with their hot breath and solutions, bent and lifted it in the form of mountains. Our geochemists and geologists have already found the oldest mountain ranges on earth (Belomorids in Karelia and the oldest granites in the state of Manitoba, Canada). These ranges are about 1,700,000,000 years old.*

Then the long history of the development of the organic world began. The diagram on page 86 shows the duration of each geological epoch.

About 500 million years ago the mighty ranges of Caledonia rose in the north of Europe; the ranges of the Urals and Tien Shan were formed 200 to 300 million years ago; the formation of the Alps lasted about 25 to 50 million years, while the last paroxysms of the Caucasian volcanoes were being extinguished and the mountain peaks of the Himalayas were rising.

Then came prehistoric time; the glacial epochs began one million years ago; the first man appeared 800,000 years ago; the last glacial epoch ended 25,000 years ago; the Egyptian and Babylonian cultures began 10,000 to 8,000 years ago; our chronology started 1,958 years ago.

It will be many more years before scientists accurately verify their remarkable timepiece. But the method has been found. One of the riddles of time has been solved and there can be no doubt that the chemist will soon be able to tell the age of each individual sample of stone, will be able to determine the time that has elapsed since it was formed.

Mr. Chemist, we no longer believe your atoms are invariable; everything is fluid, everything changes, everything disintegrates and is recreated, one thing dies and another comes into being; such is the history of the world's chemical processes in time. But man has been able to transform even the death of the atom into an instrument of cognizing the world and into a standard measure of time.

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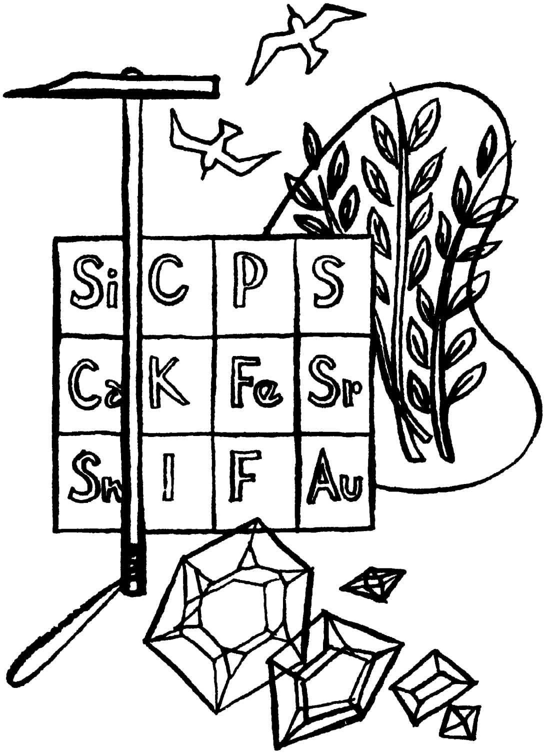
* Some American authors estimate the age of the Manitoba granites at 3,100 million years, but Soviet scientists consider these figures exaggerated. – *Ed.*

PART TWO



CHEMICAL ELEMENTS IN NATURE

SILICON—BASIS OF THE EARTH'S CRUST

Si 14
28.06

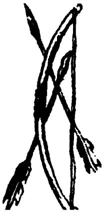
One of Zhukovsky's ballads tells us about a foreigner who came to Amsterdam and to his questions about who owned the stores, the houses, the ships and the lands received the invariable answer: "*Kan niet verstaan.*" "How rich he must be," the foreigner thought envying the man, unawares that in Dutch these words meant "I cannot understand."

I recall this story whenever I am told about quartz. I am shown most diverse objects: a transparent sphere glittering in the sun with the clearness of cold spring water, a beautiful agate of a variegated

Druse of rock crystal, the purest and most transparent variety of quartz pattern, a multi-coloured sparkling opal, pure sand on the seashore, a thread of molten quartz as thin as a silk fibre, or fireproof pottery made of the same quartz, beautifully faceted piles of rock crystal, a mysterious pattern of fantastic jasper, a petrified tree turned into flint, a crudely formed arrow-head of primitive man; and whatever my question I am told: all this is made of quartz or of minerals with a very similar composition. It is all the same chemical compound of silicon and oxygen.

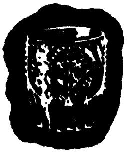
Si is the symbol for silicon, the second most abundant element in nature (oxygen is the first). It never occurs in the free state; it always forms a compound with oxygen—SiO_2, which is known as silica, or silicon dioxide.

SILICON AND SILICA



Granite contains about 80 per cent silica or 40 per cent silicon. Most hard rocks are built of its compounds. The porphyry of the mausoleum in Red Square, the beautiful granites in the revetment of the Moskva Hotel and the dark-blue sparkling labradorite facing the ground floor of some houses in Dzerzhinsky Street in Moscow, in a word, all the hard and strong rock of the earth is composed of more than one-third silicon.

Silicon is the chief constituent of ordinary clay. The common sand found on river banks, the sandstones and shales are essentially also silicon. No wonder, therefore, that about 30 per cent by weight of the entire earth's crust consists of this element and that down to the depth of 16 kilometres about 65 per cent of the crust is formed of its main compound with oxygen which chemists call silica or SiO_2 and which we most frequently refer to as quartz. We know more than two hundred different varieties of natural silica, while mineralogists and geologists use more than one hundred different names when enumerating various kinds of this most important mineral.



We speak of silicon dioxide when we name flint, quartz, rock crystal and mean the same when we admire the beauty of violet amethyst, of variegated opal or red sard, black onyx or grey chalcedony; it also includes the beautiful varieties of jasper, whetstone and ordinary sand. Most diverse names are given to the individual varieties and it probably requires a whole science to make out the compounds of this remarkable element.

But in nature we even encounter many more compounds in which our silica is combined with oxides of other metals and, thus, gives rise to thousands of new mineral varieties called silicates.

Natural pillars—individual structures of volcanic rock—basalt. Rovno Region, Ukrainian S.S.R.

Man makes use of these in his construction and in general economy; the most important of them are clays and feldspars used in the manufacture of various kinds of glass, porcelain and pottery; they are used in the production of window-panes, cut-glass and concrete, which is as strong as armour and which forms one of the chief materials in the construction of highways, bridges and reinforced concrete flooring and roofing of plants and factories, theatres, houses, etc.

Is there anything in the world that can compare in strength and diversity of its properties with silicon and its compounds in the hands of man?

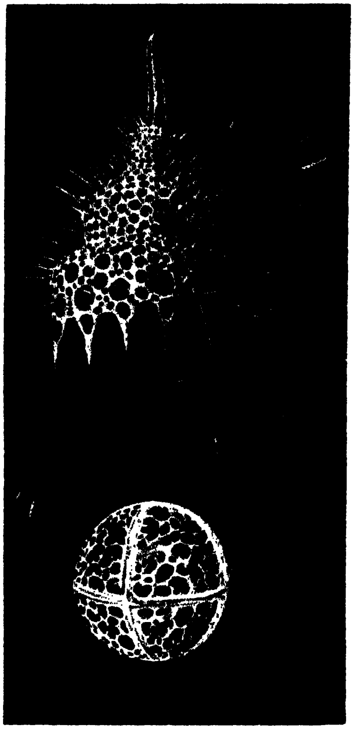
SILICON IN ANIMALS AND PLANTS

But even long before ingenious man learned to use silicon dioxide for his needs nature had made extensive use of it in the life of plants and animals. Wherever it was necessary to build a strong stalk or a firm straw of an ear the content of silica increased, and we know what a great deal of it is contained in the ash of ordinary straw and especially in the strong stems of such plants as horse-tail which grew in the distant geological carboniferous epochs rising from marshy lowlands for dozens of metres like the bamboo tubes rich in silica now rise in the gardens of Sukhumi and Batumi. In these plants nature was able to combine the law of mechanical strength with the strength of the material itself.

But the strength of the stem is of enormous practical importance not only to the ears of cereals, which it prevents from falling under the blows of wind or rain, but also to other plants.

Flowers and decorative plants are transported by planes every day; in order to prevent the flowers from crumpling and to keep their stems intact it is necessary to add readily soluble silicon salts to their soil. The plants absorb silica with water and their stems grow strong and durable.

But it is not only the stems that need the strength of silicon and its compounds. The minutest plants, diatomaceous seaweeds build their skeletons from silica, and we now know that one cubic centimetre of rock formed from the testae of these seaweeds requires about 5,000,000 of these small organisms. Particularly remarkable are the structures in which silica is used by animals to build their skeletons. Animals found various solutions for the problem of strength in the different epochs of the development of life. In some cases they protected their bodies with an external calcareous shell; in others they built this shell from calcium phosphate; in still other cases a hard skeleton instead of the shell formed the foundation of the animal, this skeleton being made of most diverse but strong materials. Sometimes these were calcium phosphates like the substance of which our bones are built; sometimes they were fine, delicate needles of barium and strontium sulphates; finally, some groups of animals made use of



Radiolaria. Pseudopodia of the living cell protrude from the openings in the elegant flint skeleton

Nature uses us in growing plants and animals
O
Si
O

Flint skeleton of a "glass" sponge about 50 cm. long

strong silica of which they built their structures. Thus, the families of radiolarians constructed their delicate skeletons from fine silicious needles.

Some sponges also form their hard parts from silicious needles—spiculae.

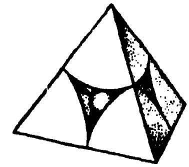
Nature contrives to use silica in hundreds of different ways to give the soft, changeable cells firm support.

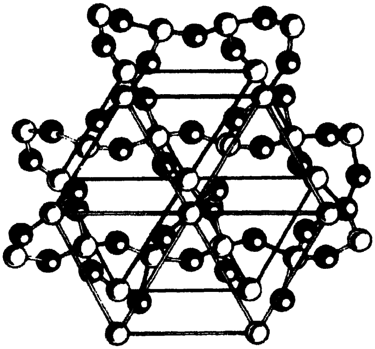
WHY ARE SILICIOUS COMPOUNDS SO STRONG?

Our scientists have been trying for some time to solve the riddle of the remarkable strength that silicon imparts to the skeletons of animals and plants, to thousands of minerals and rocks, and to the finest industrial commodities.

And when the eyes of our roentgenologists penetrated into the interior of silicious compounds they beheld remarkable pictures that revealed the reason for their strength and the riddle of their structure.

It appears that silicon contained in them is in the form of charged atoms—ions 0.000,000,004 cm. in size. These small charged globules are united with similar but larger charged globules of oxygen. As a result, four globules of oxygen, touching each other, very closely





Arrangement of atoms of silicon (white balls) and oxygen (black) in a crystal of quartz. The atoms of oxygen always bind the atoms of silicon. Frame structure

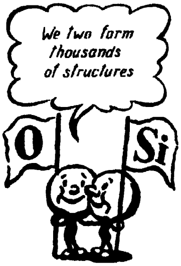
arrange themselves around each of these silicon globules and form a special geometrical figure which we call a tetrahedron.

The tetrahedrons combine with each other according to different laws and give rise to large and complex structures which it is hard to compress or bend and in which it is uncommonly difficult to break an atom of oxygen away from the central atom of silicon.

Modern science has found that these tetrahedrons may form thousands of combinations.

Other charged particles sometimes arrange themselves among them; in some cases our tetrahedrons combine into separate bands or films forming clays and talcs, but combinations of tetrahedrons are always the basis of their structures.

And as carbon and hydrogen form hundreds of thousands of different compounds in organic chemistry, silicon and oxygen form thousands of structures in inorganic chemistry; the complexity of these structures has been revealed by X-rays.


We two form thousands of structures
O
Si

Silica is not only difficult to destroy mechanically; it is not only so hard that a sharp steel knife cannot cut into the compound, but it is also stable chemically because not a single acid except hydrofluoric acid can destroy or dissolve it and only a very strong alkali dissolves silica* transforming it into new compounds. It is very hard to melt and begins to pass into the liquid state only at 1,600 to 1,700° C.

No wonder, therefore, that silicon and its various compounds form the basis of inorganic chemistry. In our time a whole science of chemistry of silicon has come into being, and the paths of geology, mineralogy, engineering and construction are interlaced with the history of this element at each step.

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* Silica is easily fused with soda; in this case the carbon dioxide of the soda is very violently liberated and a transparent globule of sodium silicate, which dissolves in water, is formed. This is why we call it soluble glass.

HISTORY OF SILICON IN THE EARTH'S CRUST

Let us now take several examples in order to trace the fate of silicon in the earth's crust. With metals it forms the basis of the molten magma in the interior of the earth's crust. When this molten magma hardens in the interior forming crystalline rock—granites and gabbro, or pours out to the surface in the form of lava streams, basalt and other rock, complicated compounds of silicon, called silicates, are formed. If there is a surplus of silicon pure quartz makes its appearance.

Here they are, the short crystals of quartz in granite porphyries or the dense smoky crystals in pegmatite veins, the last remnants of the melts of the earth's interior. If you carefully bake a piece of this "smoky topaz"* in bread or heat it to 300 or 400° C. you will get "golden topaz" with which you can make a bead or a brooch.

Here are quartz veins with white compact quartz. We know that some of them are hundreds of kilometres long. Immense quartz veins stand out like beacons on the slopes of the Urals. Veins with cavities filled with transparent rock crystal stretch for many hundreds of kilometres here. These are the pure transparent varieties of quartz described by the Greek philosopher Aristotle who gave them the name "crystal" and who connected the origin of rock crystal with petrified ice. This is the rock crystal which as far back as the 17th century was mined in the natural "cellars" of the Swiss Alps with individual cavities yielding up to 500 tons, i.e., up to 30 carloads, of rock crystal.

Individual crystals are sometimes enormously large. A crystal of rock crystal 8 metres in circumference was found on Madagascar. The Japanese turned an immense sphere more than one metre in diameter and weighing nearly 1.5 tons from Burmese transparent rock crystal.

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* The name does not quite fit since in composition "smoky topaz" is merely a quartz (SiO_2) and not a real topaz whose composition is more complex; it includes silicon, aluminium and fluorine with oxygen—$Al_2F_2(SiO_4)$.

Remains of quartz veins preserved as the most durable parts of the earth's crust during weathering. Height 30 metres

Another type of silica, which externally in no way resembles the variety we have just discussed, is precipitated from molten lava when hot silica-laden steams deposit immense masses of silicious nodules and geodes in separate veins or gas cavities. And as the rock disintegrates into clay gruss enormous balls up to one metre in diameter roll, as it were, out of it.

In the State of Oregon (U.S.A.) they are known by the name of "giant eggs." They are broken up into pieces and then sawed up into thin plates to produce beautiful laminated agates, i.e., raw material for the "rubies" of watches and other precision instruments, for the knife-edges of balances and for mortars used in chemical laboratories. Even after the cessation of volcanic activity, silica is sometimes brought out to the earth's surface by hot springs due to the presence of cooling extruded masses. Such, for example, is the origin of the "base opal" deposited by geysers in Iceland and in Yellowstone National Park in the U.S.A.

Let us take a look at the snow-white sands of the dunes on the coast of the Baltic and of the northern seas and at the millions of square kilometres of sandy deserts in Central Asia and Kazakhstan; it is sand that determines the nature of sea coasts and deserts: quartz sand now with a red film of ferric oxide, now with a prevalence of black flint and now pure white, cleaned by the sea-waves.

And here are fancy wares made of rock crystal. With the aid of various scrapers and emery powder a skilful Chinese craftsman has made fantastic articles from quartz crystals.

Wonder how many decades he spent on turning this little vase or on making this monstrous dragon, or on hollowing out this little bottle for rose oil?

Deposits of geyserite—base opal—form terraces of silicious tuff

There is an agate plate dyed different colours. Ingenious man has learned to impregnate it with different solutions, thus changing the grey, unattractive agate into brightly coloured plates to be used in the manufacture of various wares.

But here we see even more wonderful pictures: entire petrified forests in Arizona, stone tree-trunks of pure silica—agate in the Western regions of the Ukraine and amid the Permian deposits on the Western slopes of the South Urals.

Here is a sparkling stone resembling the light in a cat's or a tiger's eye. Here we have mysterious crystals inside which we see, "phantom-like," what appears to be other crystals of the same quartz. And here reddish-yellow sharp needles "Cupid's Arrows"—of the mineral rutile pierce rock crystal in every direction. Here is golden felt—"Venus' Hair." Here we see a remarkable stone with a cavity inside nearly completely filled with water. The water plays and sparkles inside the silicious shell.

Sea sand of fine crystalline grains of quartz. The purest sand is used for the manufacture of quartz glass

Here we have an incredibly tortuous tube, a result of the action of lightning on quartz sand, alloyed fulgurites, "arrows from the sky" or "thunderbolts" as the people call them. And there are stones from the sky. Singular meteorites of green or brown glass rich in silica are found in various sections of the vast zone which stretches across Australia, Indo-China and the Philippines.

To think of the controversies these mysterious formations gave rise to! Some thought these were remains of molten glass of ancient man; others believed them to be molten particles of terrestrial dust; still others considered them to be products of sands which melted when masses of meteor iron fell into them; but most scientists are inclined to believe they are real particles from other worlds.

FLINT AND QUARTZ IN THE HISTORY OF CULTURE AND ENGINEERING

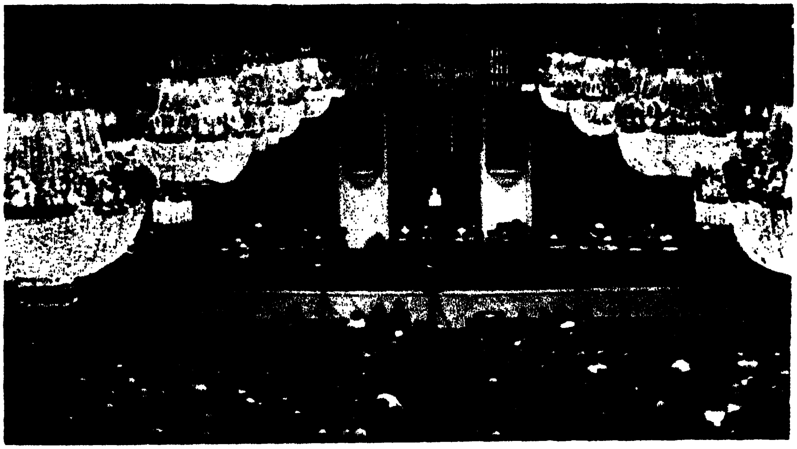
In the preceding pages I tried to paint for the reader a picture of the complex history of quartz, silica and their varieties. From the hot molten materials to the cold surface of the earth, from the cosmic regions to the sand that is strewn on our icy sidewalks, we encounter silicon and silica everywhere; we find quartz all over as one of the most remarkable and most abundant minerals in the world.

I could finish my story of quartz right here, but I want to tell you about the tremendous importance of quartz in the history of culture and engineering. It is no mere accident that primitive man made his first tools from flint or jasper. It is not without reason that the earliest decorations in the ancient Egyptian structures and in the remains of the Shumerian Culture in Mesopotamia were made precisely from quartz. It is not in vain that as early as 12 centuries B. C. the peoples of the East learned to melt sand with soda and produce glass.

Rock crystal found most extensive application with the Persians, Arabs, Indians and Egyptians, and we have information that quartz was processed five and a half thousand years before our time. For many centuries the ancient Greeks believed rock crystal to be petrified ice turned into stone by divine providence.

Many fantastic stories are connected with this stone. Enormous importance was attached to it in biblical legends. In the construction of Solomon's Temple in Jerusalem this mineral played a very important part under different names: agate, amethyst, chalcedony, onyx, sard, etc.

The first industry for processing this stone was organized in the middle of the 15th century. Man learned to cut, grind, colour and widely utilize it for decorative purposes. But this was all individual attempts of handicraftsmen and was not done on a mass scale until the new engineering made greater demands on it. Rock crystal is now extensively used in industry and in radio-engineering where supersonic waves are picked up and transformed into electric oscilla-



Crystal chandeliers at the State Philharmonic Society in Leningrad

Everything in this picture is made of quartz glas

tions by means of piezo-quartz plates. Rock crystal has become one of the most important forms of raw material for our industry.

In addition to the flute turned from rock crystal (Vienna Art Museum) and the transparent samovar (Armoury Museum in Moscow) we now have small quartz plates for the radio; these small plates are responsible for the success of one of the greatest discoveries of man—long-distance transmission of electromagnetic waves.

But quartz, i.e., pure rock crystal, will soon be made by chemists. Crystals of this mineral—small pure plates for the radio and, maybe, for our window-panes and crockery will be grown on fine silver wire at a high temperature and under great pressure in large airtight vessels filled with liquid glass.

Then the life-giving ultra-violet rays of the sun, retained by ordinary window-panes, will fill our rooms. We shall have crockery made of molten quartz and shall be able to dip in cold water quartz cups, heated on a stove, without any misgiving.

Most delicate fabrics will be woven from very fine quartz threads, so fine in fact that five hundred of them put together will be no thicker than a match stick; and silica will be the material not only for building the skeletons of the minutest radiolarians, but also for the clothes of man.

Rock crystal has become the basis of new engineering; not only the geochemist uses it as a thermometer for taking the temperature of the terrestrial processes,* and not only the physicist determines the length of electromagnetic waves with the aid of quartz; quartz offers new and tempting prospects in various branches of industry and will soon form part and parcel of our day-to-day life.

The more persistently chemists and physicists master the atoms of silicon the sooner they will write one of the most remarkable pages in the history of science and engineering, as well as in the history of the earth itself.

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* If rock crystal crystallizes at a temperature above 575°C. it forms crystals of a special appearance, i.e., hexagonal dipyramids. If it forms from solutions at temperatures below 575°C. the shape of its crystals is different: the crystals are elongated in the form of hexagonal prisms. *Ed.*

CARBON—BASIS OF ALL LIFE

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Is there anyone who has never seen a precious iridescent diamond, or grey graphite, or ordinary black coal? All these are only different forms in which the same element—carbon—is found in nature.

There is relatively little carbon on earth; its amount constitutes one per cent of the weight of the earth's crust, but it plays an enormous role in the chemistry of the earth: without it life would be impossible.

The total amount of carbon in the earth's crust is 4,584,200,000 million tons. Carbon is distributed through the earth's crust as follows:

In living substance .	700,000 million tons
In soils	400,000 million tons
In peat	1,200,000 million tons
In brown coal	2,100,000 million tons
In coal	3,200,000 million tons
In anthracite	600,000 million tons
In sedimentary rocks	4,576,000,000 million tons

We must add to this 2,200,000 million tons in the atmosphere and 184,000,000 million tons in the water of the oceans.

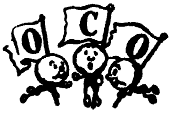
Let us look into the history of carbon, the element of which living matter is built and which is studied by a special branch of chemistry. A good deal of its migration through the earth's crust is still mysterious and vague.

At the earliest stages of its existence accessible to our research we encounter this element in molten magmas. It forms part of different rocks which have hardened in the interior and in the veins of molten

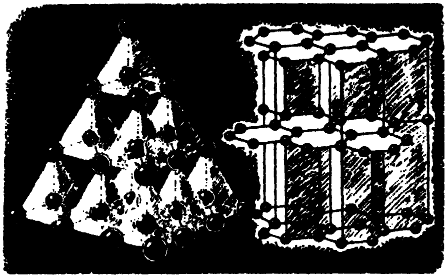
Vegetation of the Carboniferous period, from which coal was formed

masses now in the form of little leaves or globular clusters of graphite and now in the shape of crystals of precious diamonds. But the most of the carbon escapes the hardening massifs; it rises along veins as volatile hydrocarbons and carbides and produces accumulations of graphite (for example, on Ceylon) or combines with oxygen and rushes upward in the form of carbon dioxide.

We know that in the interior the omnipotent silicon dioxide prevents this gas from forming salts; as a matter of fact we do not know a single more or less important mineral containing carbon dioxide in igneous rock. But the same rocks retain it mechanically in their cavities (just as they retained solutions of chlorine salts), and these gas inclusions accumulate 5 to 6 times as much carbon dioxide as we have in our atmosphere.



In the regions of volcanoes, not only active but already long extinct, this gas broke out into the atmosphere as early as the tertiary period, now collecting in separate gas streams together with



Top: diamond and graphite consist of carbon atoms but the atoms arrange themselves in these minerals differently. In the diamond (right) each atom is surrounded equidistantly by four atoms of carbon (tetrahedrons). In graphite the atoms are arranged in layers; the atomic bonds between the layers are weak

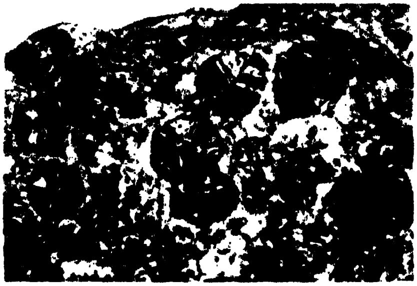
other volatile compounds and now mixing with water and forming narsans (mineral waters).

Man has made use of these waters for therapeutic purposes and has built sanatoria and hydropathic establishments near them, for example, in the Caucasus. The water in them is so oversaturated with carbon dioxide that the bubbles constantly rising to the surface create the impression that the water is boiling.

If you visit the Urals, however, you will not find any such warm carbon dioxide springs. Geochemistry explains this difference in the composition of the waters of the Urals and the Caucasus by the fact that the Urals arose much earlier than the Caucasian Mountains and the underground rocks had already cooled here during the period of mountain formation.

But in the Caucasus a focus of heat has been retained deep under the mountains. The rocks located near this focus and containing carbon dioxide (chalk and limestones) partly decompose under the influence of the heat and liberate gaseous carbon dioxide. This carbon dioxide rises along cracks to the surface together with the mineralized water.

We know cases when the underground streams of carbon dioxide are so powerful and are ejected under such high pressure that owing to their evaporation a fog and "snow" are formed of the solid carbon dioxide near the points of their exit on the



Stellate crystals of graphite in igneous rock. Ilmen Mountains in the South Urals surface of the earth. This solid carbon dioxide from the natural streams is used for technical purposes as dry ice.

There were periods in the history of the earth's crust when increased volcanic activity extruded tremendous amounts of carbon dioxide into the atmosphere; there were also times when luxuriant tropical vegetation returned a lot of carbon to its native state. The role of man with his industrial activity pales before these processes.

Enormous amounts of carbon dioxide are now thrown out by active volcanoes, for example, Vesuvius, Etna, Katmai in Alaska, etc. The gases ejected by volcanoes consist mainly of carbon dioxide.

Without me there wo ld be no life on
C

Carbonic acid begins its destructive action on the surface of the earth as a powerful factor of chemical transformations; unlike the interior here it is carbonic and not silicic acid that is master of the situation; it destroys igneous rock, extracts metals, combines with calcium and magnesium accumulating in the form of limestones and dolomites; its salts collect in water basins in immense amounts, and it is from these salts that organisms make their shells and corals build their mighty structures.

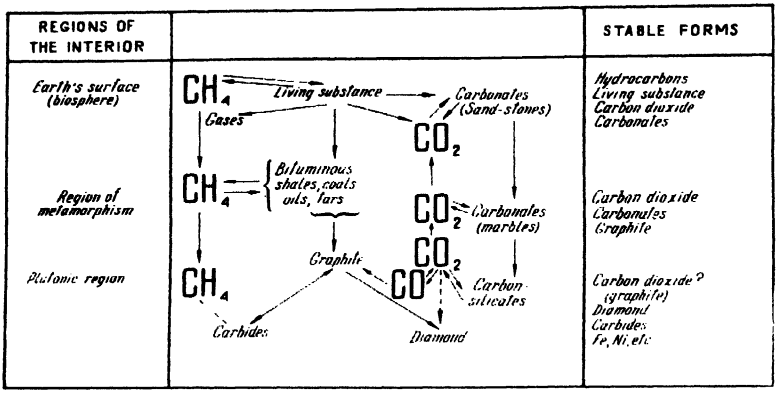
We cannot sufficiently appreciate the significance of these slow transformations of carbon on the earth's surface since they not only influence the climate on the surface, but also determine the changes in the development of the entire organic world.

Just imagine for a second what the earth would look like without carbon. It means there would not be a single tree, or green leaf or blade of grass. Nor would there be any animals. Only bare cliffs of various rocks would jut out amid the lifeless sands and silent deserts of the earth. There would be no marble and no limestones which decorate our landscapes with their white colour. There would be neither coal nor oil. Without carbon dioxide the climate of the earth would be more severe and colder since the carbon dioxide in the atmosphere promotes absorption of the luminous energy of the sun.

I am the food of industry
C

The waters, too, would be lifeless.

The chemical properties of carbon are very peculiar. It is the only element that yields an unlimited number of compounds with oxygen, hydrogen, nitrogen and other chemical elements. Many of these carbon or organic compounds themselves constitute various complex proteins, fats, carbohydrates, vitamins and many other compounds which form part of the tissues and cells of living organisms.



Geochemical cycle of carbon

The very name "organic compounds" indicates that man learned about carbon compounds when he began isolating them from the tissues of plants and animals as, for example, sugar and starch, later learning to produce many artificial compounds. Today organic chemistry which studies carbon and its compounds, their synthesis and analysis, numbers more than one million organic compounds. We may point out for comparison that our laboratories produce more than 30,000 inorganic compounds and that there are less than 3,000 natural inorganic compounds or minerals.

There are so many organic compounds that we have to give them ever longer and more complicated names; for example, acrichin, the well-known medicine for malaria, has the following full name - "methoxychlorodiethylaminomethylbutylaminoacrichin."

The capacity of carbon to yield numerous compounds is responsible for the wealth and diversity of species of plants and animals of which there are at least several million.

But this does not mean that carbon forms the main mass in the living organisms, or living substance, as we say in geochemistry. They only contain 10 per cent carbon; they are composed mainly of water (up to 80 per cent), the rest being other chemical elements.

Owing to the ability of organisms to nourish, develop and reproduce themselves, enormous masses of carbon pass through living substance in the process of life. You must have seen many times how a pond begins to be overgrown with a green film of seaweeds and other plants on the surface in the spring, how these plants fully mature in the summer and how they grow brown and settle to the bottom in the autumn forming ground silt rich in organic matter. They serve as the source, as we shall see later, of coals and vegetable silts—"sapropels" from which synthetic benzine can be obtained.

Animals give off a lot of carbon dioxide during respiration.

Thus, for example, the surface of all pulmonary alveoli in man constitutes about 50 square metres, and in 24 hours man expires an average of 1.3 kilograms of carbon dioxide.

All of mankind annually expires about 1,000 million tons of carbon dioxide into the atmosphere of the earth.

Finally, there is an even greater reserve of bound carbon dioxide underground in the form of limestones, chalk, marble and other minerals, forming layers hundreds and even thousands of metres thick. If we could return the entire amount of carbon dioxide bound up in them as calcium carbonate and magnesium carbonate to the atmosphere the air would contain 25,000 times as much carbon dioxide.

The carbon dioxide of the atmosphere partly dissolves in the water of the world ocean. From the air and the water carbon dioxide is absorbed by plants. As the amount of carbon dioxide in the water of the ocean decreases new quantities of it come from the air. The vast surface of the ocean acts as a great pump absorbing and aspirating carbon dioxide.

Plants are the first to draw carbon dioxide into the cycle of living substance. The leaves of green plants capture carbon dioxide in the light and transform it into complex organic compounds. This process is called photosynthesis and involves light and chlorophyll, the green substance of plants. The enormous importance of photosynthesis in nature was first established and studied in detail by the Russian scientist Kliment Timiryazev. In the course of a year large amounts of atmospheric carbon dioxide go through the plants. But this shortage of carbon dioxide in the atmosphere is continuously replenished by the liberation of carbon dioxide from water reservoirs and animal organisms.

Enormous masses of organic substance—tissues of plants—are formed

Open cast mining of brown coal

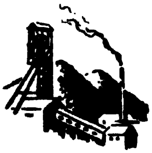
as a result of photosynthesis. Plants serve as food for animals thus ensuring their existence and development. If we add to this that oils and coals are formed from dead organisms it will become clear how important the absorption of carbon dioxide by plants is to geochemistry. There is no reaction more important in its geochemical effect than the reaction of photosynthesis in plants.

As previously stated, the carbon cycle does not end with the formation of organic compounds from carbon dioxide in plants and later in animals. Organisms die. Their bodies and tissues accumulate in large amounts in the form of deposits on the bottoms of ponds, lakes and seas and as deposits of peat. These remains of organisms are subjected to the action of water, processes of fermentation and putrefaction. Bacteria sharply alter the composition of the tissues of the organisms. Cellulose, the lignin of plants, persists most stubbornly.

The organic remains are covered up by a heavy layer of sand and clay.

Then under the influence of heat, pressure and complex chemical processes coal or oil gradually begin to be formed depending on the nature of these remains and the conditions for their preservation.

The solid organic carbon which arises as a result of the process of plant decomposition occurs in three forms: anthracite, coal and lignite.



Anthracite is the richest in carbon. Studies under the microscope confirm the vegetable origin of coal and lignite. These coals are schistous, and imprints of leaves, spores and seeds can be observed between the layers even with the naked eye. Each piece of coal is part of the carbon at one time absorbed by a cell of a plant as carbon dioxide with the aid of the energy of solar rays and chlorophyll.

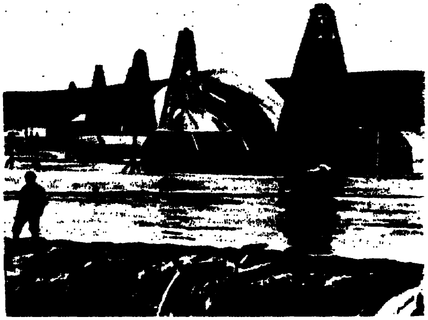
"A captured solar ray" is the way coal is referred to. As a matter of fact, each small piece of coal has retained the solar ray captured by the plant and first transformed into complex vegetable tissue and then changed in the process of slow decomposition. It heats the boilers of mills, factories and seagoing ships; its energy drives gigantic machinery and its output determines the immense development of modern industry.

The annual production of coal is expressed by the enormous figure of more than 1,000 million tons which by far exceeds the output of any other mineral. In known coal reserves the U.S.S.R. holds second place in the world, but with the growth of the country's industry these enormous reserves will only last from 100 to 200 years.

We must explore the interior of our earth in order to increase the real reserves of this valuable substance. But coal yields not only heat. Man extracts from it valuable products which have laid the basis for the chemical industry of coal. From ordinary coal man has learned to produce aniline dyes, aspirin and streptocide.

While coal was formed mainly from plant cells and tissues, such a liquid organic substance as oil was formed from other protozoa and their spores; hence, this liquid fuel, which is even more valuable than coal, is also a sort of "captured solar ray." Modern fast ships, planes and automobile transport can exist only on oil purified and refined into pure grades of gasoline. Man has learned to produce artificial benzine from certain grades of coal, but there is not very much coal fit for this purpose, the yield of liquid products is low and the quality of artificial gasoline is lower. In quest of oil man drills wells more than four kilometres deep and extracts this valuable liquid, the "black blood of the earth," from the earth's entrails.

The well, through which oil is extracted, operates for several years. Complex structures—derricks 37 to 43 metres tall—are put up on the surface. The forest of oil derricks looks very effective from afar. One can see such oilfields in the Caucasus on the western slopes of the Urals (Bashkiria), in Central Asia and on Sakhalin. There are also considerable oil deposits in Iran, Mesopotamia and in other countries.

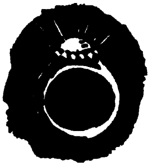


Oil fountain which formed an oil lake in the Baku fields. The fountain gushed for three years on end

Thus, this element comes from the interior to the surface again; this time it is brought out by man himself; and in the continuous struggle for existence, for the possession of the natural energy reserves, man annually burns more than 700 million tons of coal.

In order to get heat man changes everything into carbon dioxide and water again.

Agents of different orders and different significance, thus, struggle with each other now oxidizing carbon and now reducing it to its native state.



But, as previously stated, in addition to coal there are two more interesting varieties of pure carbon—diamond and graphite. How different the sparkling diamond is from the ordinary grey graphite with which we write! We always attribute differences in the properties of bodies to the differences in their composition. In this case, however, the different properties are due to different arrangement of the atoms in the crystals.

In the diamond crystal the atoms lie very close to each other. This accounts for its considerable specific gravity and hardness, which

Forest of oil derricks in a Baku oilfield exceeds the hardness of all the other minerals, as well as for its exceptionally high refraction index.

Diamond can form from molten rock only under very high pressures of 30 and, perhaps, even 60 thousand atmospheres.

Such pressures exist only at a depth of 60 to 100 kilometres. Rocks very seldom come to the surface from such depths, and this may be the reason why diamonds are encountered extremely rarely. For its hardness and sparkle the diamond is very highly valued as a first-class precious stone.

India has long been known for her diamonds mined in placer deposits. Diamond fields were discovered in Brazil (1727), in Africa (1867) and in the Soviet Union. The greater part of world's diamonds is now mined at the African deposits discovered in the valley of the Vaal River, the right tributary of the Orange River.

At first they were mined in river clay placer deposits, but it was soon discovered that they were also to be found in the blue clay on the gently sloping hills away from the river. The blue clay began to be worked and a "diamond rush" started; plots of blue clay three metres square were bought at a million times their price and very deep holes were dug. People swarmed like ants in these holes and dug the rock. Suspension ways were built in order to remove the precious clay.

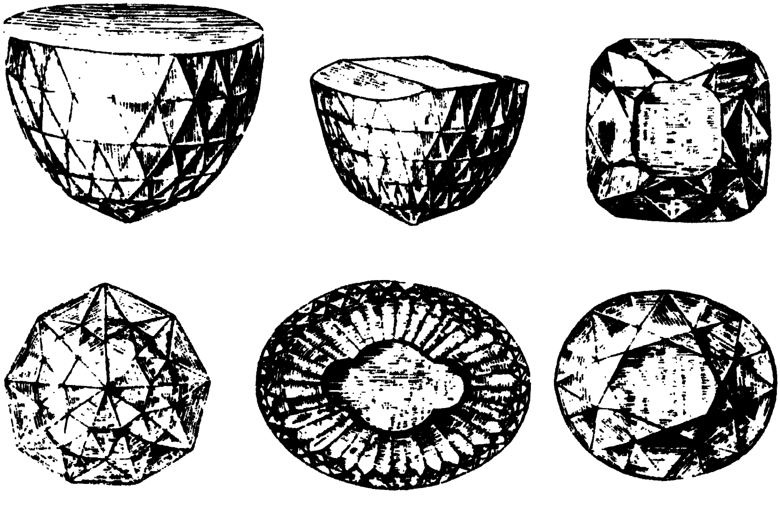
It was not very deep, however, before the clay disappeared and hard green rock known as kimberlite came into view. It also contained diamonds, but they were very

Open cast work in diamond-bearing pits in the environs of Kimberley in 1830. The picture shows numerous ropes used by the owners of small plots for hoisting the ore hard to extract and the small owners had to give up their costly and inefficient efforts. After a period of inactivity a large stock company resumed work, but this time it sank mines.

The diamond-bearing rock goes down into the interior to inaccessible depths. It fills the pipes formed during volcanic explosions.

Fifteen craters produced by these explosions are known: the largest of them is 350 metres in diameter, the rest measure from 30 to 100 metres.

Kimberlite is sprinkled with very small diamond grains weighing less than 100 milligrams (or half a carat). Large stones are also encountered sometimes. The "Excelsior" weighing 972 carats or 194 grams was the largest for a long time. An even larger diamond named "Cullinan" and weighing 3,025 carats or 605 grams was found in 1906. Stones weighing more than 10 carats are rare and expensive. The most famous diamonds weigh from 40 to 200 carats. The ordinary diamonds—crumbs, as well as the black variety—"carbonado" or the diamond drops (diamond fragments) are also very valuable because

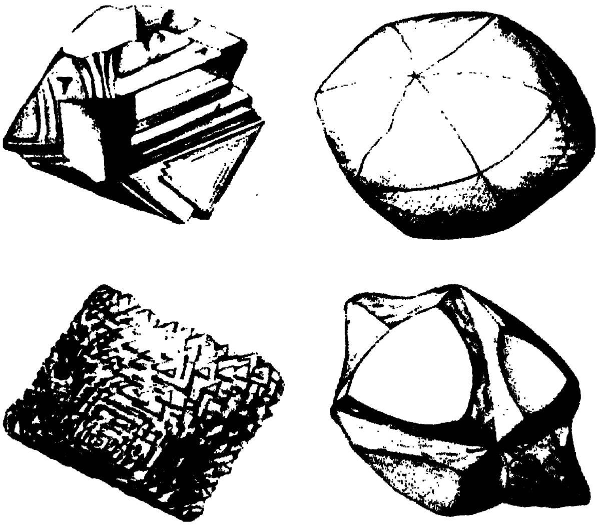


The world's greatest diamonds: (top row) "Great Mogul" weighed 780 carats on process. "Orlov"-weight 194 carats, "Regent"-137 carats; (bottom row) "Florentine"-140 carats, old and new grinding of the "Koh-i-Nor" diamond (186-106 carats) they are used in engineering for drilling and boring hard rock. The drawing machines which produce tungsten filament threads for electric light bulbs require rather large stones.

Graphite is the same carbon, but how its properties differ from those of diamonds, though!

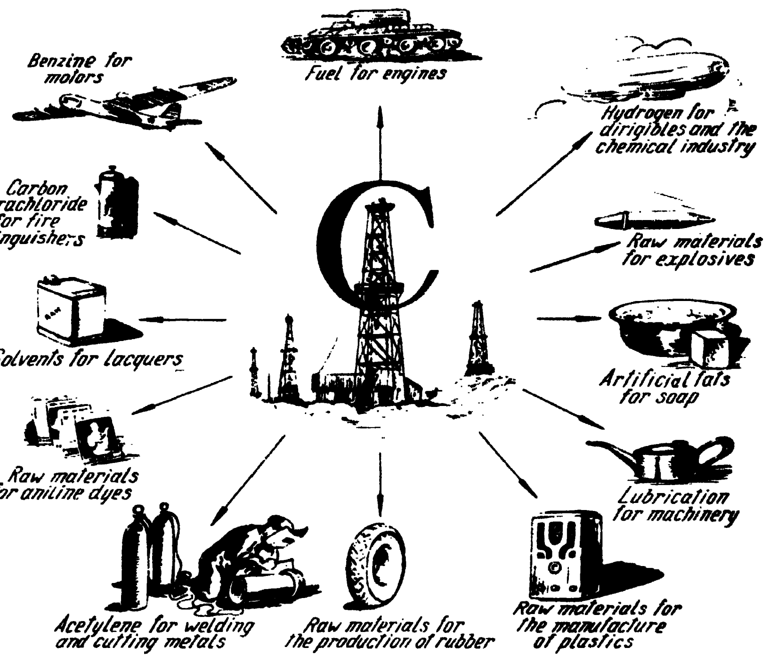
Its atoms easily separate from each other along planes. This soft mineral with a metallic lustre is not transparent, easily breaks up into small sheets and leaves a trace on paper. Graphite very poorly combines with oxygen and can stand very high temperature being a sort of fireproof material.

It is of dual origin: it is formed either by the decomposition of carbon dioxide liberated from the magma during the formation of igneous rock or by the metamorphosis of coal. A famous deposit of the first type is in Siberia. Lenses of very pure graphite are found here amid the cooled igneous rock—nephelitic syenite. Enormous deposits of graphite occur in the basin of the Yenisei River. This graphite originated from coal and is high in ash content.



Original forms of native diamonds, sketched by A. Fersman in 1911

Whenever we write in pencil we use graphite. For the manufacture of lead pencils graphite is mixed with purified clay and the hardness of the pencil depends on the amount of the latter; little clay is used for soft pencils and vice versa. The cylinders are then pressed and glued into wood. But only 5 per cent of the total graphite produced goes into lead pencils. Most of it is used to manufacture fireproof crucibles for melting the highest grades of steel,


Benzine for motors
Fuel for engines
Hydrogen for dirigibles and the chemical industry
Carbon tetrachloride for fire extinguishers
C
Raw materials for explosives
Solvents for lacquers
Artificial fats for soap
Raw materials for aniline dyes
Lubrication for machinery
Acetylene for welding and cutting metals
Raw materials for the production of rubber
Raw materials for the manufacture of plastics

Use of oil in various branches of industry. The picture shows only a small part of the different substances produced by chemical processing of oil

electric furnace electrodes, and for lubricating friction parts in heavy machinery (for example, bloomings); as a powder it is used for sprinkling the clay moulds employed in casting metal machine parts.

We should now recall the fate of the carbon dioxide that was retained in layers of the earth in the form of limestones, chalk and marble.

To begin with, how was it formed? This is easy to answer; suffice it to examine a little chalk powder under the microscope. We shall find in it a whole world of microscopic fossils. We shall see numerous circles, little rods and crystals not infrequently of a fine and beautiful pattern. These are remains of the lime skeletons of microscopic organisms—rhizopods. Some of their species are still found in the warm seas. The skeletons of rhizopods are made of calcium carbonate, and myriads of such skeletons formed the rock after the death of the organisms. But the formation of rock involves not only the lower microscopic animals; the skeletons of many other marine animals and plants are made of calcium carbonate.

These skeletons are also encountered in limestones.

By the remains of the organisms scientists can tell the time the limestones were formed.

The latest geochemical research makes it possible to determine the relation between coal and oil and the total amount of limestones in the world.

Consequently, the abundance of limestone in each geological epoch enables us to estimate the amounts of coal and oil which were then formed. These geochemical conclusions are of great importance even if the practical estimates prove inaccurate.

Many of the ancient limestones change to marble under the influence of pressure and lose all traces of organic life. The carbon dioxide accumulated in them over a period of millions of years has left its cycle. Only if mountain-forming or volcanic processes should occur anywhere near the marbles they may again release carbon dioxide under the influence of heat and give rise to its new cycle.

Thus nature itself maintains a balance in the eternal cycle of chemical processes.

PHOSPHORUS—ELEMENT OF LIFE AND THOUGHT

P 15
30.98

In order to make the history of this remarkable natural element more intelligible I shall tell you two stories. One of them will date from distant times, i.e., the end of the 17th century, the other will refer to our own days. Then I shall try to draw conclusions from these two stories and set forth the fabulous history of phosphorus without which there can be neither life nor thought.

* * *

A dark basement weakly lighted by a grated window, located high in the wall. A furnace with hearths and a large bellows, large retorts and clouds of smoke.... The walls are covered with various inscriptions, Arabic dicta, pentagrams, astronomic calculations and a picture of a starry sky and the heavenly bodies. Ancient volumes with heavy leather covers and some mysterious signs are laid out on the tables and on the floor. On the floor there are also large bowls for grinding salts, piles of sand and human bones, vessels with the "water of youth": the table is crowded with sparkling drops of mercury, fine glasses, retorts, and yellow, brown, red and green solutions.

Against this background of an old alchemical laboratory we behold the figure of a grey-haired alchemist who in his long voluntary seclusion has been trying to change silver to gold and to utilize the mysterious power of combustion to transform one metal into another.

He has been dissolving powders and human bones in a thousand different ways, evaporating the urine of man and various animals; he has been searching for the philosopher's stone which would make

Medieval alchemist in his laboratory

old people young and would teach man to produce costly gold from ordinary metal.

It was under these mysterious and complex conditions that the alchemists of the 17th century were trying to work out the problems of chemistry. But the attempts to produce gold from mercury or to obtain the philosopher's stone from human bones proved futile. Time wore on and the experiments brought no results. The alchemists surrounded their laboratories with ever greater mystery and hid their recipes and the thick volumes of their notes.

In 1669 Lady Fortune finally visited one of the alchemists working in Hamburg. In search of the precious stone he took fresh urine, evaporated it dry and annealed the black residue. At first he heated this residue gently, then more and more strongly; a white wax-like substance began to collect at the top of the tube, and the alchemist noticed, much to his surprise, that the substance was luminescent.

Hennig Brandt (that was the alchemist's name) long kept his discovery absolutely secret. Other alchemists vainly tried to gain access to his laboratory. The powers that be came to Hamburg in an endeavour to buy his secret. The discovery created a tremendous impression; the greatest minds of the 17th century took an interest in it believing that the philosopher's stone had been found. This stone shed a cold, quiet light; it was given the name of "cold light," while the substance itself was named "phosphorus" (which means "light-bearing" in Greek).

R. Boyle

Robert Boyle and Leibniz took considerable interest in Brandt's discovery. Very soon one of Boyle's pupils and assistants in London attained such wonderful results that he even advertised in a newspaper: Hankwitz, London chemist, address so and so, prepares all sorts of medicines. In addition he informs all those who are curious that he is the only one in London capable of producing all varieties of phosphorus at 3 pound sterling per ounce.

And still the production of phosphorus remained a secret of the alchemists until 1737. Their attempts to utilize this remarkable element were fruitless. Believing they had discovered the philosopher's stone

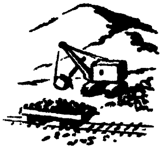
General view of apatite deposits

they vainly tried to use this luminescent white phosphorus in changing silver to gold. The philosopher's stone would not reveal its secret properties, while the explosions which sometimes occurred during experiments only frightened the investigators. Phosphorus remained a mysterious substance and found no application for itself. It took nearly two centuries before Liebig, a chemist, discovered in his modest chemical laboratory one more mystery—the significance of phosphorus and phosphoric acid in the life of plants. It became clear that phosphoric compounds were the basis of life in the fields, and the idea that compounds of the "cold light" should be strewn over the fields to improve the crops was voiced for the first time in this laboratory.

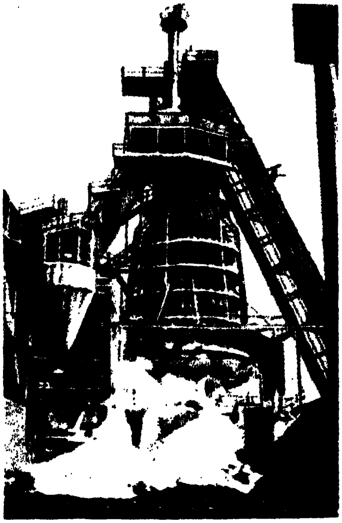
LIEBIG

We know the mistrust with which these words of Liebig were treated. His attempts to fertilize the soil with saltpetre were useless, and the cargo of this salt brought by ships from South America found no buyers and was dumped into the sea. The possibility of using the salts of the "cold light" for the purpose of increasing the yield of rye and wheat and for developing the stem of the valuable fibrous plant—flax—was long considered a mere fantasy. It took years of persistent scientific work again before phosphorus became one of the most important chemical elements in agriculture.

* * *



My second story deals with 1939. In the U.S.S.R., apatite, a light green stone and very valuable mineral, is mined on a large scale on the slopes of snow-covered mountains in the north. It is produced in tremendous quantities and its output vies with that of the phosphorite extracted on the Mediterranean Coast, in Africa and in Florida. Apatite goes to large concentration plants where it is pulverized and separated from harmful constituents; the result is a pure white powder, as soft and friable as flour. Then it is loaded into railway trucks and dozens of trainloads of it are sent from the distant Arctic regions to factories in Leningrad, Moscow, Odessa, Vinnitsa, Donets Basin, Perm and Kuibyshev where it is treated with sulphuric acid and transformed into a new substance, another white powder—a soluble phosphate fertilizer. Millions of tons of these phosphates are strewn by special machines over the fields of our country doubling the yield of flax, increasing the sugar content of sugar-beets, multiplying the number of cotton bolls and improving the vegetable crops.



Blast-furnace for sublimation of phosphorus

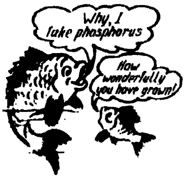
Dispersed over the fields the minutest atoms of phosphorus get into the bread, vegetables and other foods we consume. Calculations show that in each piece of bread weighing 100 grams we consume up to 10,000,000,000,000.000,000,000 atoms of phosphorus, i.e., a figure so enormous that it is hard to call it in ordinary language.

We have told you about the country's main source of phosphates, the apatite of the Khibiny Mountains. But immense as the mines on Kola Peninsula are they cannot alone provide enough phosphate for the vast fields of the Soviet Union because of transport limitations. The number of trainloads of precious apatite that reach Siberia, Kazakhstan and Central Asia does not suffice and here newly discovered deposits come to the aid. Phosphorites are now vigorously mined in many sections of the European part of the Soviet Union; no less important deposits are now known in Siberia and in Central Asia. New deposits are being prospected for and worked in various parts of the country. The phosphorite deposits make it possible to secure scores of millions of tons of phosphate fertilizer which brings its life-giving force to the country's state and collective-farm fields and fully impregnates the grains in the ears and the stems ot the plants with its vivifying atoms.

We have painted two pictures from the history of phosphorus: its discovery and its utilization in our days. More than ten million tons of phosphate fertilizer is annually produced in the world; of these two million tons are strewn over the fields.

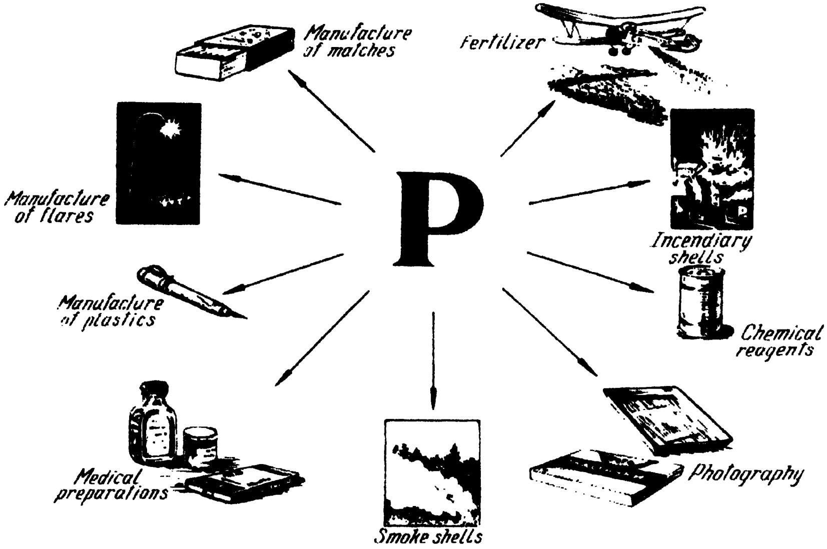
But phosphorus is used not only for fertilizer. The importance of this substance increases with each passing year. At the present time this "cold light" is used in at least 120 branches of industry.

In the first place phosphorus is the substance of life and thought; the content of phosphorus in the bones determines the growth and normal development of the cells of the bone marrow and is, in the long run, responsible for the strength of the living organisms. The high content of phosphorus in the cerebral matter indicates its essential role in the work of the brain. Phosphorus deficiency in the food leads to a weakening of the entire organism. The existence of a number of different medicines and pharmaceutical preparations containing phosphorus for the weak and the convalescents is no mere accident. Not only man needs phosphorus; plants and animals also require enormous quantities of it. Man has learned to fertilize with phosphorus not only the land but the sea as well. Fertilization of sea-water with phosphorus in enclosed bays and gulfs rapidly increases the reproduction and growth of seaweeds and other microscopic organisms which leads to an increased reproduction of fish. We have personally witnessed experiments in which phosphorus was introduced into ponds near Leningrad as a result of which the fish grew to twice their former size. Phosphorus has lately played a very important part in the preparation of various foods and, especially, mineral waters. High grades of mineral waters are obtained with the aid of phosphoric acid. Phosphates, especially those of manganese and iron, produce strong and durable coatings. We know that high-quality wares of stainless steel are made by a special method of coating with phosphates. The surfaces of planes can be rendered stainless with the aid of such phosphate coatings. The "cold light" of phosphorus created in its time one of the largest branches of industry, namely, the match industry. Our young readers do not know the phosphorus matches used before the matches of our time were invented. I still remember since my childhood the boxes of phosphorus matches which were made with red heads and lighted by rubbing against some object. People particularly liked to light these matches against the soles of their shoes. However, the dangerous properties of phosphorus necessitated the invention of other matches, the ones we are using today.


Why, I take phosphorus
How wonderfully you have grown!

The use of phosphorus in matches suggested the idea of utilizing this substance for a cold fog rather than for a cold light. When burning phosphorus changes to phosphoric acid which drifts in the air for a long time in the form of a mist.

Military engineering has made use of this peculiarity of phosphoric acid for creating smoke-screens. Incendiary bombs contain a considerable amount of phosphorus, and in modern warfare phosphoric bombs



Use of phosphorus in different branches of industry

spreading a white cold fog have become one of the means of attack and destruction.

We shall not weary you with the complex chemical course travelled by phosphorus in nature, from the melts deep in the interior of the earth to the fine apatite needles and the living filters (micro-organisms) which absorb phosphorus from its weak solutions in sea-water.

The history of migration of phosphorus in the earth's crust is uncommonly interesting. The fate of phosphorus is bound up with the complex process of life and death. But phosphorus accumulates where organic life terminates and animals die en masse, at the junction of sea-currents where submarine cemeteries are formed. In the earth phosphorus accumulates in two ways: either in the deep deposits of apatite separated from the hot molten magma or in the remains of the skeletal parts of animals. The atom of phosphorus goes through a complex cycle in the history of the earth. Separate links of its migrations have been discovered by chemists, geochemists and technologists. Its past fate is lost in the deep interior of the earth; its future is in world industry.

SULPHUR—BASIS OF THE CHEMICAL INDUSTRY

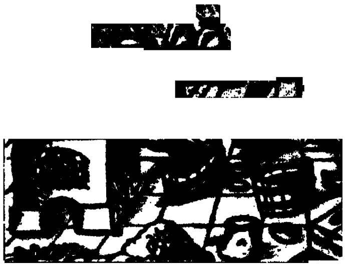
S 16
32.06

Sulphur is one of the first chemical elements known to man. It was encountered in many places along the Mediterranean Coast and could not escape the attention of the ancient peoples—the Greeks and Romans. Volcanic eruptions invariably brought a lot of sulphur to the surface; the odour of sulphur dioxide and hydrogen sulphide was considered a sign of the activity of Vulcan, the underground god. The clear, transparent crystals of sulphur in the large Sicilian deposits were noticed many centuries B.C. The ability of this stone to liberate asphyxiant gases attracted special attention. It was precisely because of this unusual property that sulphur was considered one of the basic elements in the world at that time.

No wonder, therefore, that to the minds of ancient naturalists and especially alchemists sulphur always played an exceptional role in the processes of volcanic activity or formation of mountain ranges and lodes.

At the same time it appeared to the alchemists that sulphur possessed a mysterious property of liberating new substances during combustion and should, therefore, have been the missing constituent of the philosopher's stone which they so vainly tried to find in order to be able to produce artificial gold.

The idea of the exceptional role of sulphur in nature is excellently con-



Phosphorus smelting in the Middle Ages

Old engraving of Vesuvius

veyed in the famous treatise of the Russian scientist Lomonosov entitled "On Terrestrial Layers" and published in 1763. The following are a few quotations from the treatise:

"In considering the great deal of underground fire the mind immediately turns to cognition of the matter which it contains." . . . "Is there anything that can burn better than sulphur? What can keep up and feed a fire with greater force than sulphur?" "What combustible matter comes more abundantly than sulphur out of the earth's interior?"

"Because it is not only from the jaws of fire-breathing mountains that it belches forth, and in hot springs that spurt out of the earth and in dry underground vents that it accumulates in great amounts,

Sulphur hills in the Kara Kums. Turkmen S.S.R.

but because there is not a single ore and hardly a stone which by mutual friction with another does not give off a sulphurous smell thus announcing its presence.... Taking fire in the entrails of the earth and expanding the heavy air in the abysses it presses against the earth lying above, lifts it and by moving it in different directions and in different amounts, produces different quakes and primarily breaks through wherever it finds the least resistance, shooting in the air the light parts of the destroyed earth's surface which in falling take up the near-by fields, while the others, because of their enormity, overcome the fire by their gravity and coming down form mountains.

"We have observed a great deal of fire in the bowels of the earth and an abundance of sulphur which it requires for burning and which suffices for earthquakes and for producing great alterations—calamitous but also useful, terrible but also bringing delight."

True enough, the earth's interior contains a lot of sulphur and in cooling it gives off many volatile compounds of various metals in combination with sulphur, arsenic, chlorine, bromine and iodine. We can judge about this not only by the odour typical of volcanic eruptions, of asphyxiant *soffioni* in South Italy or of the clouds of sulphur dioxide of the Kamchatka eruptions; sulphur is also brought out in

solutions and it forms lodes. Together with arsenic and antimony, its friends and fellow-travellers in these hot volatile fluids, it forms the minerals from which man has obtained zinc and lead, silver and gold since time immemorial.

But on the earth's surface these dark, opaque, lustrous polymetallic ores and various glances and pyrites are subjected to the action of atmospheric oxygen and of water; the latter decompose the sulphides into new compounds, oxidizing the sulphur into sulphur dioxide. We know this gas by the odour of sulphur matches. With water it forms sulphurous and sulphuric acids.

Sulphur and its products are similarly liberated during oxidation of large pyrite lenses, they destroy the surrounding rocks and, combining with stabler elements, finally yield gypsum or other minerals. It will be noted that sulphuric acid, which is formed in pyrite deposits and where native sulphur is mined, possesses destructive properties.

I recall the Mednogorsk Mine in the South Urals where so much sulphuric acid is liberated during the oxidation of pyrite that it is absolutely impossible to guard oneself against its poisonous activity and the workers' clothes do not last long because the acid eats holes in them.

When we worked in the Kara-Kum sands (Turkmen S.S.R.) we did not know this property of sulphur deposits, and when our samples of sulphur ore neatly wrapped in paper came to Leningrad we found that the paper was entirely eaten away, that only scraps of the labels remained and that even the boxes were damaged. We had to describe the hero of these calamities, the natural sulphuric acid, as a new independent liquid mineral.

Dunes of gypsum sand

The Kara-Kum ore is noted for the fact that it consists of a mixture of sand and sulphur. To obtain pure sulphur P. Volkov, Soviet chemical engineer, proposed an ingenious method. Fine ore is put into a boiler working under high pressure, water is added, the boiler is hermetically sealed and steam under a pressure of 5 to 6 atmospheres is passed through it. The temperature in the autoclave rises to about 140° C., the sulphur melts and collects in the lower part of the boiler while the clay and sand are stirred up by the steam and carried to the top. A tap is opened some time later and the sulphur quietly flows into special trays. The entire process of melting takes about two hours. Soviet engineers solved the problem of purifying Kara-Kum sulphur as simply as all that.

Sulphur does not keep its initial form long: it soon combines with various metals and in volcanic regions forms accumulations of alunite which is dispersed around active volcanoes in white spots or bands.

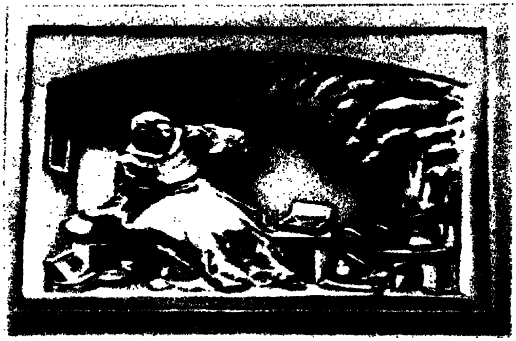
Some astronomers believe that alunite is responsible for the white haloes and the white rays which surround the craters of the lunar mountains.

A large amount of oxidized sulphur is in combination with calcium. The resulting compound is rather hard to dissolve in the laboratory but it is a sufficiently mobile compound in the earth. This compound, which we call gypsum, is deposited in large quantities as thick layers in salt-lakes and in drying sea basins.

But the history of sulphur on the earth's surface does not end with this. Part of the sulphuric acid changes into a gas again; a number of micro-organisms reduce sulphur; hydrogen sulphide and volatile gases are formed from the solutions of its salts and are brought out to the surface in very large amounts by oil-bearing waters; they saturate the air in marshy lowlands and in a number of firths and lakes form a black silty mass which is called curative mud and is extensively used for therapeutic purposes in the Crimea and the Caucasus.

A very great part of the sulphur volatilizes as hydrogen sulphide, thus, returning to a mobile form. This ends one of the periods in the complex cycle of this element in geological history.

But man has sharply



Explosion of powder

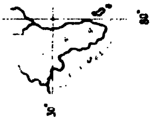
At a match factory. Matches before packing

changed the paths which sulphur travels on earth, and it has become one of industry's most valuable materials. Only a million tons of it is mined annually in its pure state, but in iron compounds from which sulphur is obtained for acid it is mined in scores of millions of tons annually.

Sulphur has become the basis of the chemical industry and we should be hard put to it to name all the branches of industrial engineering for which it is indispensable. I shall mention only the main branches, but these examples are enough to show that industry cannot exist without sulphur.

Sulphur is required for the production of paper, celluloid, paints, most medicines, matches, for the purification of benzine, ether and oils, and for the manufacture of phosphate fertilizers, vitriols, alum, soda, glass, bromine and iodine. Without it it is hard to produce nitric, hydrochloric and acetic acids; hence, it is clear why sulphur has played an enormous part in the development of industry since the beginning of the 19th century. As sulphuric acid we need it for the production of dynamite, while its use in gunpowder has made it absolutely indispensable to fire-arms.

The struggle for sulphur stands out, therefore, all through the history of the 18th century. Sicily was long the only supplier of sulphur. It was part of the Italian kingdom and since the beginning of the 18th century British frigates had repeatedly bombarded the Sicilian coast in an endeavour to capture this wealth. Then the Swedes discovered a method of producing sulphur and sulphuric acid from pyrites. The vast Spanish pyrite deposits became the centre of attention of all European states and the British frigates appeared at the Spanish coast in order to seize this source of sulphur and sulphuric acid, as well. The Sicilian deposits were neglected and all attention was focused on Spain.

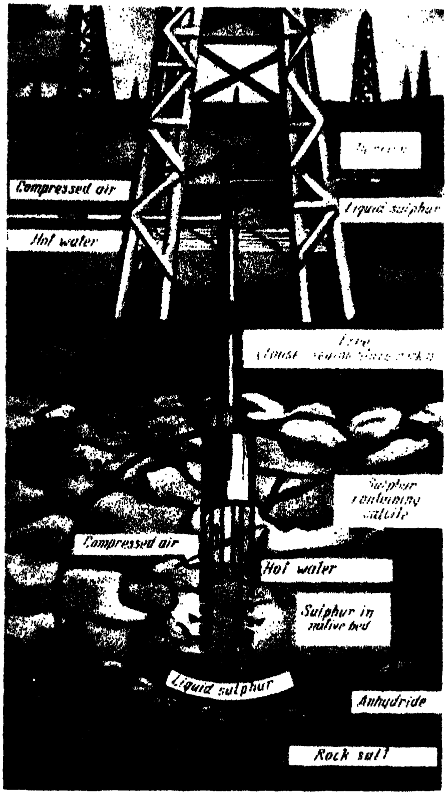


Then the first and extremely rich sulphur deposits were discovered in Florida.

In pursuit of higher productivity a seemingly incredible method was proposed: superheated steam was pumped underground; owing to the low melting temperature of sulphur (119° C.) the steam melted it underground and forced it to the surface in a liquid state.

The first installation for pumping out molten sulphur was built and the sulphur was ejected to the surface where it solidified into large hills.

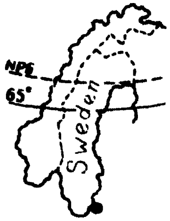
This method is very productive and enormous amounts of sulphur were obtained by it in America. The Italian and Spanish deposits receded into the background. Once again a brilliant idea occurred to the Swedes in the polar country of sulphurous ores. One of the plants began to produce sulphur as a by-product while processing pyritic ores.

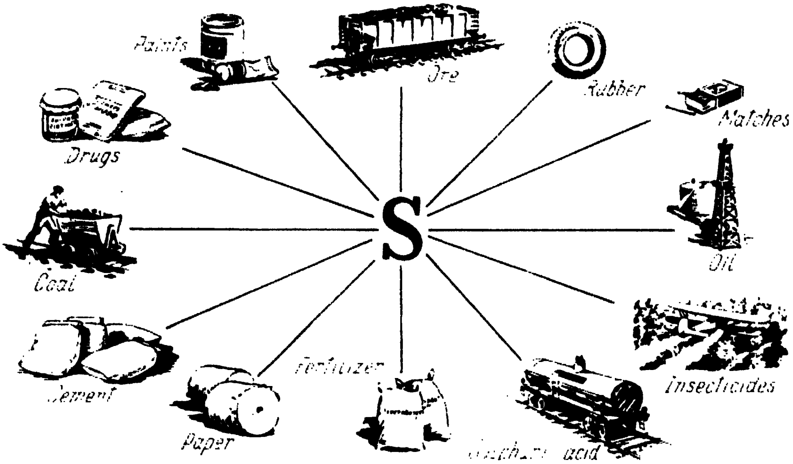


Installation for sulphur extraction from a deep bore hole. Superheated steam and compressed air are pumped through double pipes into limestones, which contain sulphur, and melt the latter. Liquid sulphur rises along ring space in the pipes and pours out to the surface where it hardens in the form of enormous rectangular monoliths

Again a metal sulphide has become the source of sulphur and again the fate of sulphuric acid has changed.

I am telling you this to show you how intricately creative ideas sometimes change the use of a substance in industry. These new methods will remain in the history of science: they have radically changed





Use of sulphur in various branches of industry

the techniques of sulphur extraction and have influenced certain production relations. It is not without reason that one of the Italian journals wrote that the new methods "killed" the population of Sicily forcing it to starve by growing oranges on its poor plantations and grazing goats in its parched mountain pastures.

CALCIUM—SYMBOL OF DURABILITY

Ca 20
40.08

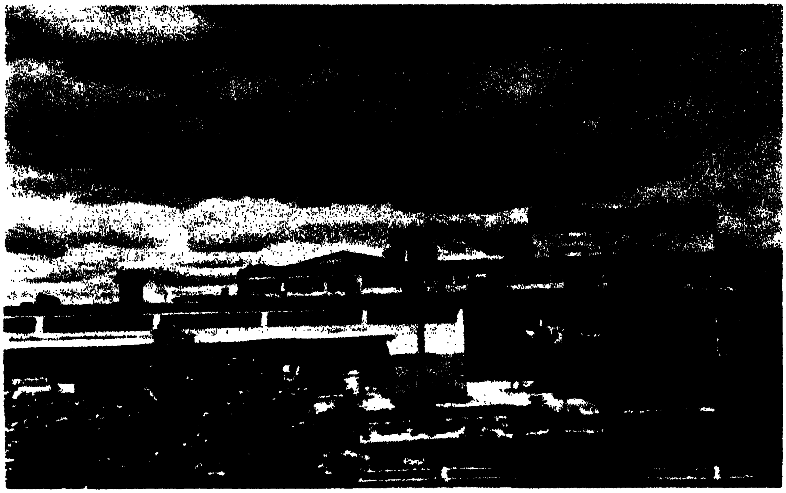
One day, as I was passing through Novorossiisk, I was asked by a group of engineers and technicians working at the large cement plants located near the city to lecture at their club on limestones and marls which are the principal raw materials for cement.

I had to tell them that I did not know anything about the subject. I knew very well that various kinds of limestones formed the basis of lime and cement; I also knew how valuable good lime and cement were; I told them how hard it was to get these two necessary products for the construction jobs in the North.

Simple lime was usually ordered from the Valdai Hills fifteen hundred kilometres away from the construction sites, while cement came from Novorossiisk in a roundabout way, across the Black, Aegean and Mediterranean seas, and the Atlantic and Arctic oceans; I told them that that was why I very well understood how terribly important lime was to life and construction, but that personally I never had anything to do with limestones and knew nothing about them.

"Then tell us about calcium," one of the engineers said, thus emphasizing that the metal known as calcium was the basis of all limestones. "Tell us about this metal from the point of view of geochemistry, its properties, its fate, where and how it accumulates, and why it is precisely this element that creates the beauty of marbles and imparts such valuable technical properties to limestones and cement marls."

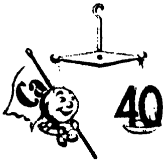
I gave them a lecture on this subject, and this is how the story of calcium atoms in the universe, which I am going to tell you, came about.



General view of a cement plant

I told them that since they were working in the cement industry, the industry of binding substances, one of the most important branches of the building industry, the history of calcium atoms should be of special interest to them.

Chemists and physicists say that in Mendeleyev's system calcium occupies a very specific place under number 20. This means that it consists of a nucleus, i.e., minutest particles—protons and neutrons, and twenty free negatively charged particles known as electrons.



Number 40 denotes the atomic weight of this element located in the fourth series of the second group of Mendeleyev's system. To form stable molecules in its compounds it requires two negative charges. As the chemists say, it has a valence of two.

You must have noticed that in what I said I used figures which are multiplies of four. In geochemistry these are very important numbers. We know that in life, too, when we want to make something stable we always use these numbers; for example, a table has four legs. A stable body, any structure, is usually symmetrical so that the right and the left halves are similar.

The numbers 2, 4, 20 and 40 tell us that calcium atoms are exceptionally stable, and we do not know yet how many hundreds of millions of degrees it would take to destroy this durable structure of the small nucleus and the group of the twenty negative planets speeding around it. And as the astrophysicists begin to understand the structure of the entire world the enormous part the calcium atoms have played in the universe comes increasingly to the fore.

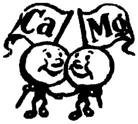
Here is the corona during a solar eclipse. Even the naked eye can see the immense prominences, the extrusion of red-hot speeding particles of metals for a distance of hundreds of thousands of kilometres; calcium plays the principal part among these. Perfect methods have now enabled our astronomers to find out what fills the interplanetary spaces. The entire space amid the dispersed stellar nebulae is pierced by speeding light atoms of certain chemical elements, and it is again calcium which along with sodium plays a big part among them.

And then obeying the laws of gravity certain speeding particles of the universe travelling their intricate routes come flying to our earth. They fall in the form of meteorites, and again calcium plays a tremendous part in them.

On our earth, too, we could hardly think of any metal of greater importance to the formation of the earth's crust and the creation of life and technical progress.

As far back as the time when the molten masses boiled on the surface of the earth, when the heavy vapours gradually separated out and the atmosphere formed, and when the first drops of water condensed and created the great oceans and seas, calcium, together with its friend magnesium, which is as dense and strong and as even-numbered an element (its number is 12), is one of the most important metals on earth.

In the different rocks, which poured out to the surface or hardened in the interior, the atoms of calcium and magnesium played a special part. The floor of the large oceans, especially the Pacific, are still paved with basalt in which calcium atoms are very important, and we know that our continents float on this basalt bed which forms a sort of thin, hard crust on the melts of the interior.



Geochemists have even estimated that the composition of the earth's crust includes 3.4 per cent calcium and 2 per cent magnesium by

Marble quarry

weight. They have linked the laws of calcium dispersion with the remarkable properties of the calcium atom itself, with the even number of its electrons and with the wonderful stability of this beautiful and perfect structure.

Immediately after the formation of the earth's crust these atoms began their complicated migrations.

At that time of the distant past volcanic eruptions brought out large masses of carbon dioxide to the exterior. The heavy clouds of the atmosphere saturated with vapours of water and carbon dioxide surrounded the earth and destroyed the earth's surface removing the still hot masses of the earth in the wild primary storms. Thus, the most interesting stage in the history of migrations of calcium atoms began.

With carbon dioxide calcium yielded strong, stable compounds. In a surplus of carbon dioxide the calcium carbonate was transported by water; with a loss of carbon dioxide it was deposited in the form of a white crystalline powder.

That is how the thick layers of limestones were formed. Wherever the sediments on the surface of the earth accumulated the remains of clays, layers of marls were deposited. The stormy movements of the molten underground masses, which broke into the layers of limestone, roasted them with their vapours at a temperature of thousands of degrees and transformed them into the snow-white mountains of marble whose proud peaks blend with the snow.

And then out of some complex clusters of carbon compounds came the first lumps of organic matter. These jelly-like colloid masses resembling the medusas of our Black Sea gradually grew more complex and new properties, properties of the living cells, arose. The great laws of evolution, the struggle for existence and for the further development of the genus rendered these molecules more complex, led them to new combinations and

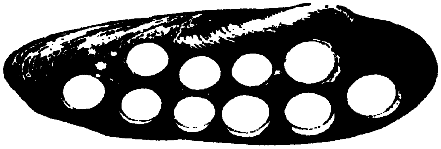
Coral polyps in the ocean

Nests of white ants—termites—built of calcium carbonate. Africa

new properties arose on the basis of the great laws of the organic world. Life was gradually taking form, first as simple cells in the hot seas and oceans, then as more complex multi-cellular organisms all the way up to man, the most perfect organism on earth. This gradual complication in the growth of each organism always reflected the struggle for the creation of a strong and stable body. In a number of cases the soft and elastic body of an animal could not resist its enemies who tore it to pieces and destroyed it at each step. In the process of gradual evolution organic substance increasingly strove to protect itself. What was required was either some impenetrable shell around the soft body to hide the animal, or a strong internal frame, the thing we call a skeleton, so that the soft body might hold firmly on the hard bones. And the history of life shows us that in this search for a hard and durable material calcium has played a very specific part. Calcium phosphate was the first to be drawn into the shells and the first shells encountered in the earth's crust were made of the mineral known as apatite.

It was not the best way, however. Phosphorus is needed for life itself and its reserves are not everywhere so large as to enable the animal to build a strong shell. The history of the development of the animal and plant world has shown that it is of greater advantage to build the strong parts from other insoluble compounds—opal, barium sulphate and strontium sulphate, but calcium carbonate proved the most suitable material.

True, phosphorus proved no less necessary, and as various types of molluscs and crawfish, as well as unicellular organisms started to make extensive use of calcium carbonate for their pretty shells the



Shell of a fresh-water mollusc used for manufacture of buttons skeletal parts of terrestrial animals began to be built of phosphates. The bones of man or of large animals are made of calcium phosphate which in its nature very much resembles our mineral apatite. But in the former, as well as in the latter case, calcium has played an appreciable part. The only difference is that the skeleton of man was being built of the phosphate of this metal, while the shells were built mainly of its carbonate.

Shells of molluscs are extracted from the sea by dragging. Used in the cement industry as pure $CaCO_3$ and for the manufacture of buttons

It is hard to think of a more remarkable picture than the one that presents itself to a naturalist as he comes to the coast of, say, the Mediterranean.

I remember when as a young geologist I found myself for the first time on the rocky shore of Nervi, near Genoa. I was amazed at the beauty and multiformity of shells, parti-coloured seaweeds, hermit crabs with their beautiful little limestone homes, various molluscs, whole colonies of sea-mosses and various limestone corals.

I was completely immersed in this wonderful world of transparent bluish water through which I could see irridescent compounds of the same calcium carbonate. But my reveries in this new world were interrupted by an enormous octopus, which came up to our rock unnoticed, and I began to tease it with a stick.

Calcium accumulated in shells and skeletons on the floors of sea basins in hundreds of thousands of forms. There the intricate remains of dead organisms formed whole cemeteries of calcium carbonate, the foundation of new rock, entire future mountain ranges.

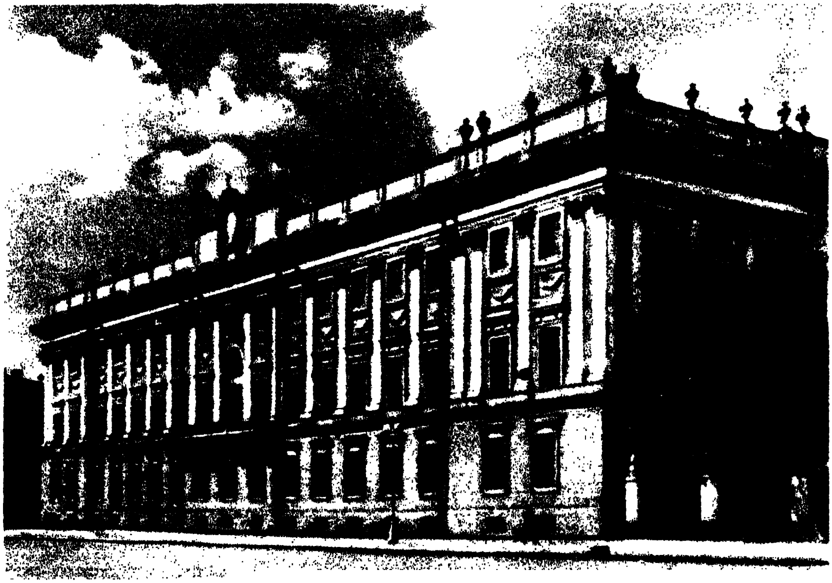
And now when we admire the multiformity of marble colours which decorate our architectural structures, or delight at the beautiful grey or white marble of the switchboard at an electric station, or go down the stairs of our Metro with their yellow-brown steps made of the Shevardino marble-like limestone found near Moscow, we must not

forget that the basis for all these enormous accumulations of limestone was laid by a small living cell and by the complex chemical reaction which catches the dispersed calcium atoms in sea-water, changes them into hard crystalline skeletons and fibres of calcium minerals that were given the names of calcite and aragonite.

But we know that the migrations of calcium atoms do not end with that.

The waters dissolve the calcium again and its spherical ions resume their migrations in the earth's crust in complex aqueous solutions now forming so-called hard, calcium-rich waters, now precipitating together with sulphur in the form of gypsum and now crystallizing into stalactites and stalagmites, the complex fantastic formations in limestone caves.

Then begins the last stage in the history of calcium-atom migrations: man takes possession of calcium. He not only uses marbles and limestones



The Marble Palace, Leningrad branch of the Lenin Museum. With the exception of the ground floor (built of granite) constructed entirely from Russian marble in their pure form, but in the large furnaces of the cement plants and in the lime kilns he releases calcium from the power of carbon dioxide and creates large amounts of cement and lime without which we would have no industry.

Sculpture of a girl. Made of white Urals marble by S. Konenkov

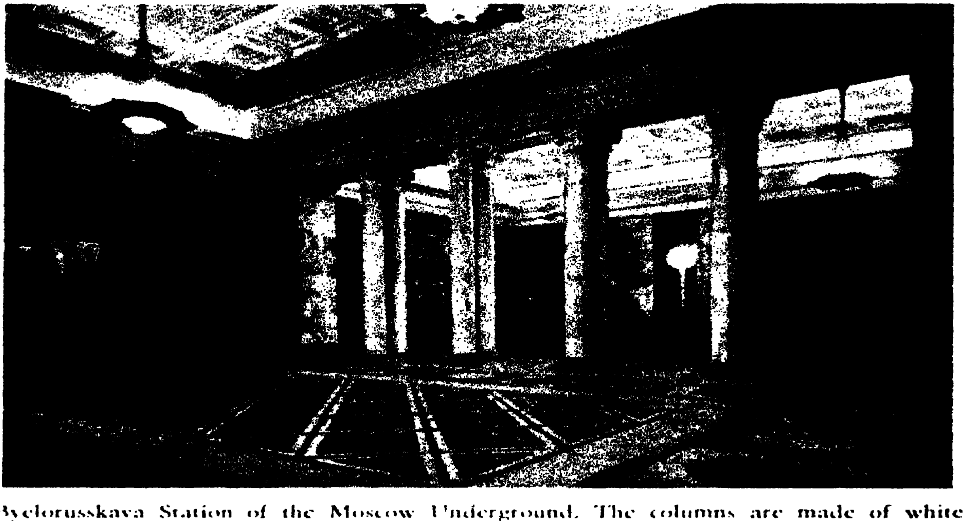
In the most complex processes of pharmaceutical, organic and inorganic chemistry calcium plays an enormous part and determines these processes in the laboratories of chemists, technologists and metallurgists. But even this no longer satisfies man. There is too much calcium around us and this stable atom can be used for even finer chemical reactions: man spends scores of thousands of kilowatts of electric power on it: he not only frees the calcium atoms in limestone from the carbon dioxide, but also severs its bond with oxygen and produces it in its pure form, i.e., in the form of a shiny, sparkling, soft and resilient metal which burns in the air and covers itself with a white film of the same lime.

And it is precisely this affinity for oxygen, this close and strong bond which is established between the atoms of the calcium metal and the atoms of oxygen that man makes use of. He introduces the metallic atoms of calcium into molten iron and instead of using various other complex deoxidizers and a number of methods of purifying pig iron and steel from harmful gases he makes the metallic atoms of calcium do this work by utilizing them in open-hearth and blast-furnaces.

Thus the migration of this element is resumed; its metallic particles do not sparkle long for they are again transformed into complex oxygen compounds more stable on the surface of our earth.

As you see, the history of calcium atoms is much more complicated

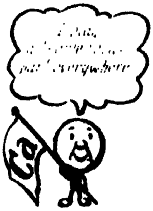
Kaluzhskaya Station of the Moscow Underground. The walls are faced with white Urals marble



Byelorusskaya Station of the Moscow Underground. The columns are made of white marble, the walls and the mosaic floor are laid out of multi-coloured domestic marbles than we think; it would be difficult to find another chemical element which travels such intricate routes in space and which determines more important moments in the origin of our worlds and in our industrial life.

We must not forget that calcium is one of the most vigorous and mobile atoms in the universe, that it has unlimited possibilities of combining into crystalline structures and that man will make many new discoveries in which he will be able to use these mobile globules for developing new materials for building and industry perhaps never before equalled in strength.

But this still requires a lot of work and a greater insight into the nature of this atom. To make a good geochemist and be able to chart a new course in geology one must be a thoughtful chemist and physicist and an expert in geology. To be a good technologist and understand the new ways of industry, the paths which will lead to brilliant victories over nature and to the widest possible utilization of the most abundant elements of the earth, one has to master the sciences of chemistry, physics, geology and geochemistry.



POTASSIUM—BASIS OF PLANT LIFE

K 19
39.096

Potassium is a characteristic alkali element which occupies a rather low place in the first group of Mendeleyev's Periodic Table. It is a typical odd element because its characteristic indices are odd; its atomic number, i.e., the number of electrons constituting its electron shell is 19 and its atomic weight is 39. It forms strong bonds only with one atom of a haloid, for example, chlorine; it is, as we say, univalent. As an odd element potassium is at the same time characterized by the considerable size of its charged spherical particles and this together with their odd number is responsible for their constant tendency to migration and their special mobility.

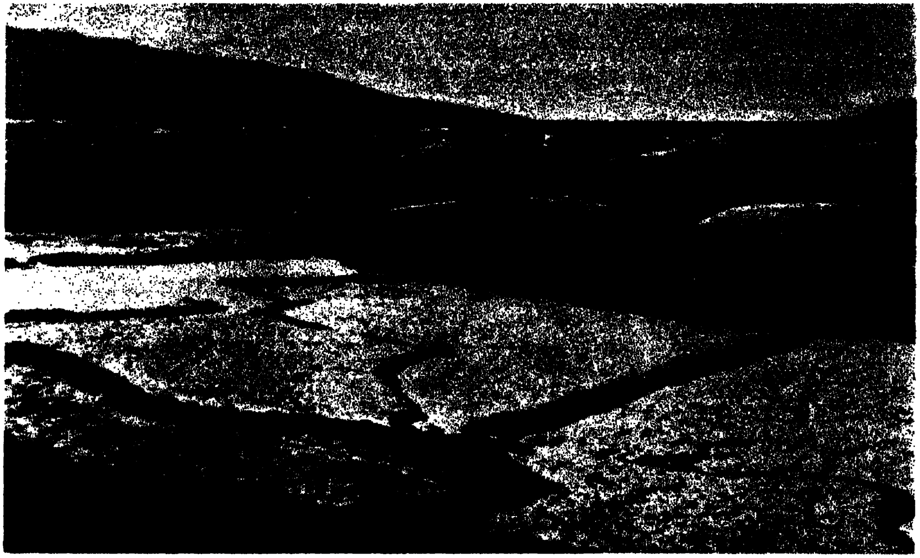
No wonder, therefore, that the entire history of potassium in the earth is connected, like the fate of its friend sodium, with exceptional mobility and complex transformations. It forms more than one hundred minerals in the earth's crust and, in small amounts, part of a hundred other mineral species. Its average content in the earth's crust is close to 2.5 per cent. This is a large figure and it shows that along with sodium and calcium potassium belongs to the elements which prevail in the earth.

The history of potassium in the complex geological past of our planet is very interesting. It has been studied in detail and we can now trace the entire course traversed by potassium atoms until they complete their complex life cycle and return to the beginning of their migrations.

When the molten magmas harden in the interior of the earth and individual elements are distributed according to their mobility, according to their ability to migrate, to form volatile gases or mobile fusible particles we find potassium among them. It does not precipitate in the first crystals which are formed before others in the interior of our earth; we scarcely encounter it in green olivine-containing Plutonic rocks which make up continuous zones of the earth's interior. Even in the basalt masses which form the ocean floor we encounter no more than 0.3 per cent potassium.

In the course of the complex crystallization of molten magmas the more mobile atoms of the earth accumulate in their upper parts; here we find more of the small heavily-charged ions of silicon and aluminium; here we also have many odd atoms of the alkalis potassium and sodium and volatile water compounds. The rocks we call granites are formed from these molten remains. They cover vast sections of the earth's surface representing the continents floating on basalts.

The granites harden in the interior of the earth's crust and potassium accumulates in them in amounts constituting nearly two per cent, and mainly forms part of the mineral we call feldspar or orthoclase. Potassium is also a constituent of the well-known black and white micas; in some places it accumulates in even greater amounts forming



Lake-salt in the pool of the Karakol salt works, Tajik S.S.R.

Across the salt bed of Lake Baskunchak

large crystals of a white mineral, called leucite, of which particularly big quantities are contained in the potassium-rich lavas in Italy where it is mined for the purpose of producing potassium and aluminium.

The granites and acid lavas of igneous rock are thus the cradle of potassium atoms on earth.

We know how they are destroyed on the surface of the earth by water, air and the carbon dioxide with which the atmosphere and the water are saturated, and how roots of plants grow through them corroding individual minerals by the acids they liberate.

Those who have ever been in the environs of Leningrad must have seen how easily granites disintegrate at their outcrops and in boulders, how their minerals are weathered, the rock loses its lustre and pure quartz sands accumulate in the form of dunes as remains of the once powerful granite massifs. Feldspar disintegrates at the same time. The potent agents of the earth's surface extract the sodium and potassium atoms from it and leave a peculiar skeleton of laminated mineral forming complex rocks which we call clay.

At this moment our two friends—potassium and sodium—begin their new migrations. Incidentally, they are friends only until this moment because after the destruction of the granite each of them begins living its own life. Sodium is easily washed out by water; there is nothing to retain its ions in the surrounding silt-containing clays and sediments. These ions are carried away by streams and rivers into large seas where they form the sodium chloride which we call common salt and which is the principal initial product of our entire chemical industry.

But potassium has a different fate. In sea-waters we find it only in small quantities. There is about the same number of sodium and potassium atoms in rocks, but of one thousand potassium atoms only two reach the sea-basins, while the other 998 are absorbed by the soil and remain in silts and in the sediments of marshes and rivers. The soil absorbs potassium and this constitutes its miraculous force.

Academician K. Gedroitz, well-known soil scientist, was the first to divine the geochemical nature of the soil. He found in it the particles which retain different metals, especially potassium, and demonstrated that the fertility of the soil in large measure depended on the potassium atoms which are so lightly and so loosely connected with it that each plant cell could absorb these atoms and make use of them for its own life. And it is by absorbing these lightly-bound, seemingly free-hanging, potassium atoms that the plant develops its sprouts.

Research has shown that the roots of plants readily extract potassium together with sodium and calcium.

Plants cannot live without potassium. We do not know yet why they cannot nor what part potassium plays in the plant organism, but experiments have shown that without potassium the plants wither away and die.

Incidentally, it is not only plants that need potassium; the latter also forms an essential part of animal organisms. Thus, for example, the muscles of man contain more potassium than sodium. Especially large amounts of potassium are contained in the brain, the liver, the heart and the kidneys. It will be noted that potassium is particularly important during the growth and development of the organism. The human adult requires much less potassium.

Potassium begins one of the cycles in its migrations from the soil. It is extracted from the soil by the roots of plants, is accumulated in their dead remains, partly passes into the organism of man or animals and is again returned with the humus to the soil from which it was extracted by a living cell.

The greater part of potassium travels precisely this route, but individual atoms manage to reach large oceans and together with other salts to determine the salinity of sea-water, though the

Evaporating pools at the Saki Salt-Works in the Crimea. The brine rich in potassium and bromine is evaporated here

latter contains 40 times as many atoms of sodium as potassium.

Here is where the second cycle of the migrations of potassium atoms begins.

When large regions of oceans begin to dry out because of the movements of the earth's crust they give rise to separate shallow seas, lakes, firths, lagoons and bays, and form salt-lakes like Lake Saki or the lakes near Yevpatoriya on the Black Sea coast. On hot summer days water evaporates so greatly that the salt precipitates, is carried ashore by waves and sometimes accumulates on the bottom of absolutely dry lakes in the form of a glittering white sheet. It will be observed that the salts precipitate in a certain sequence: calcium carbonate crystallizes first and is followed by gypsum (calcium sulphate) and sodium chloride, i.e., common salt. A brine which is greatly saturated with salts and which is known as "rapa" in the South of the U.S.S.R.

Harvesting in fields fertilized by potassium, phosphorus, and nitrogen salts remains; this brine contains scores of per cent of various salts and, especially, salts of potassium and magnesium.

Potassium happens to be even more mobile than sodium; the properties of its large spherical atoms manifest themselves and it continues its migrations until an even hotter sun evaporates the lakes to the very end, until white and red potassium salts are precipitated on the surface of salt deposits; it is in this manner that potassium deposits are formed.

Very large accumulations of potassium salts, which man so badly needs for industry, sometimes form in the earth's crust. Here it is no longer the mysterious forces of the soil and not plants that determine the route to be travelled by potassium; nor is it the southern sun that accumulates it on the shores of salt-lakes; here in industry it is man himself who is the agent of the new and enormous cycle in the migrations of its atoms.

Studying the role of potassium and phosphorus in plants Justus Liebig, one of the greatest German chemists, uttered the following winged words about 100 years ago: "Our fields cannot be fertile without these two elements." An idea, fantastic for its time, crossed his mind; it occurred to him people should fertilize their fields by artificially introducing various salts—potassium, nitrogen and phosphorus—into the soil after estimating the amounts the plants could utilize.

His idea was met with distrust by the farming people of the middle of last century; it was considered a "scientist's fancy," especially since the saltpetre, which was brought by sailing vessels from South America and which he proposed for utilization as fertilizer, was excessively expensive and found no market. Sources of phosphorus were unknown, while the grinding of bones proposed by Liebig yielded extremely costly fertilizer. People did not know how to make use of potassium and only rarely collected the ashes of plants and strewed them over the fields. The farmers of the Ukraine have long been burning the remains of maize stalks and scattering the ashes, thus obtained, about the fields; the significance of these ashes to the crops occurred to them spontaneously without the aid of science.

Many years have passed since then and problems of fertilization have acquired great importance in all countries; fertility of the soil now largely depends on whether man is able to introduce into the soil sufficient amounts of the substances which the plants have extracted

from it and which man has taken away from the fields in the form of grain, straw and fruit. It now appears that potassium has become one of the most necessary elements of farming.

Suffice it to say that in 1940 such countries as Holland used up to 42 tons of potassium oxide per hectare. True, this figure is much lower in other countries; only about four tons per hectare is used in America.

And mankind has faced the problem of finding large deposits of potassium salts, of learning to extract them and to manufacture fertilizer from them.

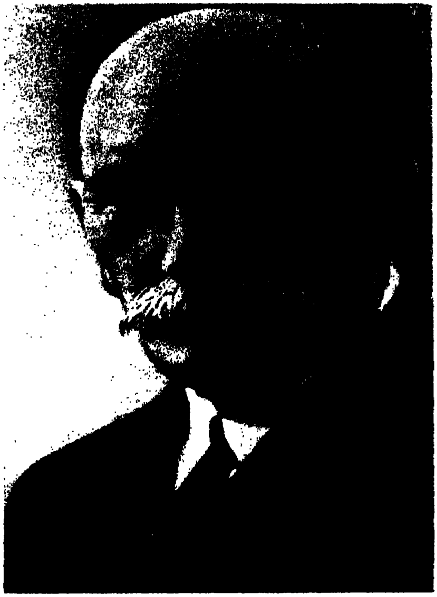
Germany long owned the world's potassium industry. Deposits of the famous Stassfurt salts were discovered on the eastern slopes of the Harz Mountains and hundreds of thousands of trainloads of potassium salts were transported from North Germany to all countries.

The other countries, for which farming was a question of vital importance, could not put up with it. North America spent a lot of time and energy before it found a small potassium deposit. The French made some headway by discovering potassium in the Rhine Valley; while potassium was being searched for the potassium minerals of the igneous rock found in Italy were made use of. But all this was insignificant compared with the amounts required by the exhausted soils.

Russian explorers tried for many years to find potassium deposits in Russia. Individual conjectures proved fruitless until the persistent work of a whole school of young chemists supervised by Academician N. Kurnakov resulted in the discovery of the world's largest potassium deposits. The discovery was accidental, but accidents in science are usually the result of long and laborious preparation, while the "accidental discovery" is nearly always merely the last step in the lengthy struggle for the effectuation of a definite idea and a reward for a protracted and persistent search.

This also holds true of the discovery of potassium. Academician Kurnakov had studied the country's salt-lakes for many decades and his mind persistently searched for the remains of the ancient potassium lakes. While working in the laboratory on the composition of salt from old Permian salt-works Nikolai Kurnakov noticed in some cases a high potassium content.

On a visit to one of the salt-works he observed a small piece of brown-red mineral which reminded him of the red potassium salts, the carnallites of the German deposits. True, the personnel of the salt-works were not sure where this piece had come from and whether it had not been from the collection of the salts they had received from Germany. But Academician Kurnakov took the piece, put it in his pocket and went to Leningrad. Upon analysis he found much to everybody's surprise that the piece was potassium chloride.



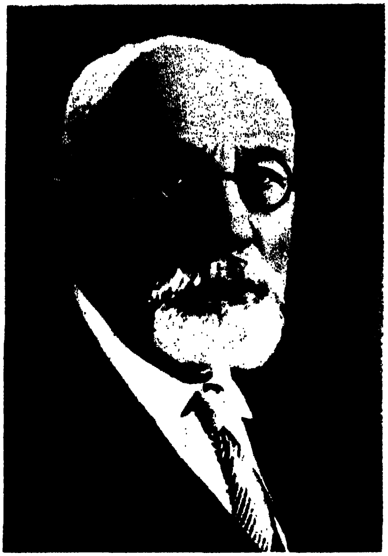
Academician Nikolai Kurnakov (1860-1941)

The first strike was made, but that was not enough; it was still necessary to prove that this piece of potassium had come from the entrails of the Solikamsk earth and that there were large deposits there. A hole had to be bored, some salt extracted under the difficult conditions of the twenties and its composition studied.

P. Preobrazhensky, one of the most prominent geologists of the Geological Committee, undertook to do the work. He pointed out the necessity of boring deep holes, and soon these holes reached thick layers of potassium salts, thus opening a new era in the history of potassium over the entire surface of the earth.

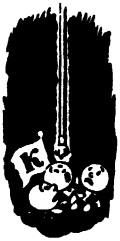
Now that several decades have passed since this discovery the picture of distribution of the potassium reserves among all countries of the world has completely changed. We find the greater part of these reserves in the Soviet Union; in terms of potassium oxide Germany owns only 2,500 million tons, Spain—350 million, France—285 million, while America and the other countries have very little potassium. Not all of the potassium deposits in the Soviet Union have been studied, however.

It is quite probable that the U.S.S.R. will soon increase its reserves and new pictures of potassium migration in the ancient Permian seas 300 to 400 million years ago will be revealed.



Geologist P. Preobrazhensky (1874-1944)

This distant past in the geological history of our country is now pictured as follows: The ancient Permian Sea covered the entire East of the European part of the Soviet Union. This sea was the shallow southern portion of the ocean that spread over the country from the North. Its separate bays and gulfs reached Arkhangelsk on the White Sea and Novgorod. In the East the sea bordered on the Urals, while in the southwest its arms stretched as far as the Donets Basin and Kharkov. In the southeast it reached far south to the regions of the Caspian. Some scientists even believed that in the beginning of its existence our Russian Permian Sea merged with the great Thetis Ocean which engirded the earth in the distant past of the Permian epoch. This large ocean gradually grew shallow forming separate lakes along its coast, while the humid climate was replaced by the winds and the sun of the deserts.



The young Urals Mountains were being destroyed by powerful hot winds; everything was being moved to the shores of the dying Permian Sea. The sea was receding to the south. Gypsum and common salt were accumulating in the lakes and firths in the north, while the content of potassium and magnesium salts was increasing in the south. The brine which man obtains artificially in the sedimentary basins, for example the Saki Lake, was accumulating in the southeast. Separate shallow seas and lakes saturated with residual salts of potassium and magnesium were thus gradually formed.

Deposits of potassium salts began to accumulate. Separate potassium deposits hidden under the soil stretch from Solikamsk to the southeast Urals. Everywhere the bore holes run into powerful underground lenses of common salt overlaid by potassium salts.

Sylvinite, a rock consisting of layers of sylvite and halite. Solikamsk deposit

A small piece of brown-red salt noticed by the keen eye of a scientist in the laboratory of the works thus led to the solution of one of the greatest problems, the problem of potassium. The country was now in a position not only fully to provide the fields with fertilizer and to increase their yield, but also to create a new potassium industry and to produce the most diverse potassium salts so indispensable to chemical production. These are potassium hydroxide, carbonate, nitrate, perchlorate, chromate and other diverse compounds increasingly used in the national economy. Large amounts of magnesium are obtained as "waste products" along with potassium; a lustrous light metal is isolated from these waste products by electrolysis, while one of its alloys, known as "electron,"* opens a new page in the field of railway and aircraft construction.

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* The alloy electron should not be confused with the electron which is a particle of negative electricity; this is only an accidental coincidence of terms.

The country's agrochemists are now realizing their dream of producing enough potassium oxide in order fully to provide our fields with this valuable substance and to increase their yield.

Such is the history of potassium in the earth and in the hands of man.

But this element has another small feature to which we should turn our attention. Curiously enough one of the isotopes of potassium possesses radioactive properties (very weak, to be sure), i.e., it is unstable; this isotope emits various rays and changes to atoms of another substance, which in subsequent groupings forms atoms of calcium.

This phenomenon could not be demonstrated for a long time, but it turned out later that this very potassium-40 really played an important part in the life of the earth because considerable amounts of heat were liberated during the transformation of the unstable potassium atoms into atoms of calcium. Soviet radiologists have estimated that at least 20 per cent of the heat formed in the earth under the influence of atomic disintegration is produced by the salts of potassium and, hence, the enormous role played by the disintegration of the potassium atoms in the thermal resources of the earth.

Naturally, biologists and physiologists tried to find out the importance of these properties to the life of the plant itself and gave expression to the idea that the miraculous and as yet incomprehensible love of the plants for potassium was due to the fact that by their radiations the atoms of potassium exerted some special influence on the life and growth of the cell.

Many experiments were conducted in this direction but so far they have failed to produce any definite results. These disintegrating atoms of potassium and their radiations in all probability play a significant part and are responsible for a number of peculiarities in the growth and development of the living cell and of the whole organism.

Such are the pages from the geochemistry of potassium, this odd, migrating chemical element. Such is the history of its migrations and cycle on earth.

A similar story of migrations in the interior of the earth, on its surface and in industry can be told about every chemical element, but for many of them individual stages in their history still escape the scrutiny of the investigator; only separate historical excerpts can now be written for many elements, and it is up to the geochemist of the future to combine them into a harmonious and consistent story. The history of potassium is more obvious because all the epochs in the life of this important element are clear to us.

Not only do we know its history, but we also have in our hands a powerful instrument for finding its deposits and for the technology of its use; the only thing that is still mysterious to us is the role it plays in the living organism, perhaps the most interesting and most important page in its history.

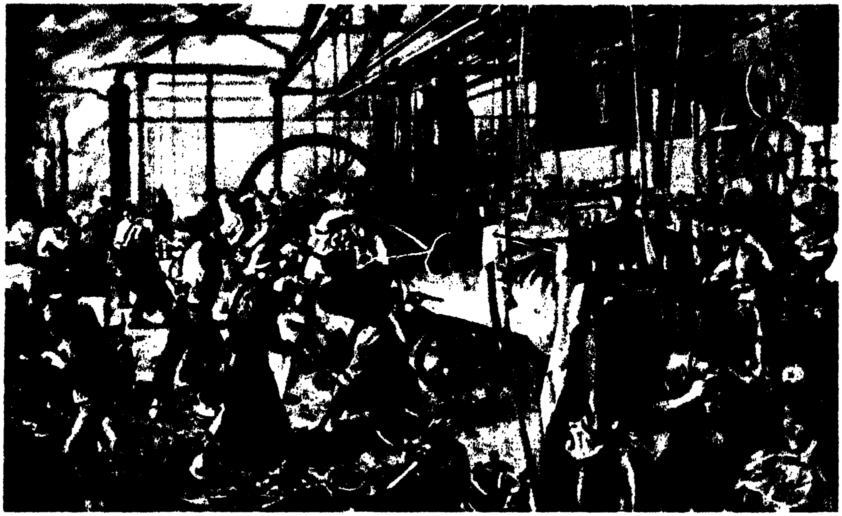
IRON AND THE IRON AGE

Fe 26
55.85

Iron is not only the main metal in nature; it is the basis of culture and industry, the instrument of war and of peaceful labour. It would be hard to find in Mendeleyev's Periodic Table another element so bound up with the past, present and future fortunes of man. Pliny the Elder, one of the first mineralogists of ancient Rome, who died in 79 A. D. during the eruption of Vesuvius, smothered by "the ashes and dust erupted by a fire-breathing mountain" as the Russian mineralogist Vasily Severgin wrote about him more than 100 years ago, expressed himself very beautifully about iron.

In his fine translation we read some brilliant pages from the history of iron as it occurred to Pliny: "Iron ores give man an excellent and at the same time a most harmful instrument. It is by means of this instrument that we till the earth, plant bushes, cultivate fruit-bearing orchards and by shearing wild vines make them grow younger with each passing year. It is also with this instrument that we build houses, crush stones and use iron for many similar purposes. But it is with the same iron that we fight battles and loot; and we use it not only close-by, but also throw it by strong hand or shoot it in the form of feathered arrows. The contrivances of the human mind are, in my opinion, the most vicious thing. In

Alchemical symbol for iron used in the Middle Ages



Picture of an old iron works (19th century)

order that man be killed the sooner, death has been given wings and feathers have been attached to iron. Man alone and not nature is to blame for this."

Since about the fourth millennium B. C., when man first mastered this metal, the struggle for iron has never ceased in the history of man. In the beginning man may have picked up the stones that fell from the sky (meteorites) and made his wares from them, like the Aztecs of Mexico, the Indians of North America, the Eskimos in Greenland and the inhabitants of the Near East. It is not without reason that the ancient Arab legend tells us that iron is of celestial origin. In the language of the Copts it is even called "sky-stone"; reiterating the ancient Egyptian legends the Arabs used to say that drops of gold fell from the sky to the Arabian Desert; on earth this gold changed to silver and then to black iron as punishment to the tribes that fought for the possession of the heavenly gift.

It was a long time before iron could be extensively used because it was difficult to smelt it out of the ores and there were very few stones, i. e., meteorites, falling from the sky.

Only in the first millennium A. D. did man learn to smelt iron ores and the bronze age was replaced by the iron age which in the history of culture has lasted to-date.

In the complex history of the peoples the struggle for iron, as also for gold, has always played an enormous role, but neither the medieval metallurgists nor the alchemists could gain real mastery over the metal; man began to master iron only in the 19th century, and it gradually became one of the most important metals in industry. As metallurgy developed, the small primitive iron-smelting furnaces were replaced by blast-furnaces which gave rise to giant metallurgical plants with a capacity of thousands of tons.

The iron-ore deposits have become the basis of the wealth of individual countries. The enormous iron reserves of several thousand million tons in Lorraine were the reason for the struggle among the capitalists. We know that in the seventies of last century France and Germany fought for the possession of the vast ore reserves of the Rhine deposits.

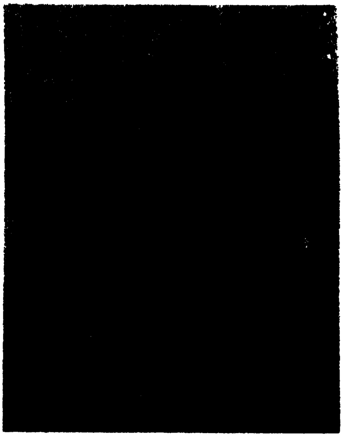
We witnessed the episodes in the struggle between England and Germany for Kiirunavaara, this remarkable mine in Polar Sweden that annually yields up to 10 million tons of excellent iron ores. We know how Russia gradually discovered and mastered her iron resources beginning with Krivoi Rog and the Urals and all the way up to the large iron reserves in the deposits of the Kursk Anomaly.

A blast-furnace at the Magnitogorsk Plant

The numerous deposits in the Soviet Union create the might of the country's industry by supplying it with metal for rails, bridges, locomotives, agricultural machinery and other tools for peaceful labour. The figures of annual pig iron and steel production now run into many millions of tons.

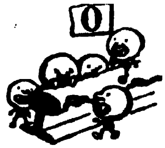
In the struggle for metal new ways for the development of modern metallurgy can already be discerned.

Iron and steel are often replaced by new varieties of high-grade steel, and the rare metals—chromium, nickel, vanadium, tungsten and niobium—added to the alloys in amounts of tenths of one per cent enhance the properties of the metal making it hard, unyielding and stable.

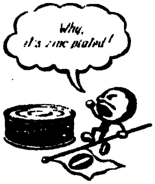


Geode of limonite (brown hematite) from the Bakal Mine in the South Urals. It was formed by disintegration of iron carbonate (siderite). Collection of the Sverdlovsk Mining Institute Museum

In an effort to improve the properties of metal and to obtain new chemical reactions in the enormous blast-furnaces and foundries man is solving one of his basic problems in the fight for iron. Iron is slipping from the hands of man; it is not gold that accumulates in the safes and banks and only an insignificant part of which is lost. Iron is unstable on the surface of the earth, in our surroundings; we know ourselves how easily it rusts. Suffice it to leave a piece of wet iron in the open and we soon find it covered with rusty spots; should we fail to cover an iron roof with a coat of oil paint, rust will eat out big holes in the iron inside of a year. In the earth we find iron tools of the old ages transformed into brown hydrous oxides; spears, arrows and armour are all ruined, subject to the great chemical law of iron oxidation under the influence of the oxygen contained in the air. Man is now facing a task of exceptional importance, the task of safeguarding his iron.



Man not only improves the qualities of metal by the additions I mentioned, but also covers iron with a coating of zinc or tin, changing it to white metal; man chromium-plates and nickel-plates various parts of machines, covers the metal with different paints and treats it with phosphates. Man uses various methods to prevent the iron from oxidation by the moisture and oxygen in our surroundings. And we must say this is no easy matter; he invents new methods using


Why, it's zinc plated!

zinc and cadmium and replaces tin by other metals. But the natural chemical processes occur spontaneously and the more iron man extracts from the entrails of the earth, the more he develops his ferrous metallurgy, the greater will be the need for safeguarding this metal.

How strange it seems to speak about safeguarding iron when there is so much of it around. Meanwhile, geological congresses were held recently and having estimated the iron reserves geologists pointed at the impending iron shortage; they predicted the exhaustion of the world deposits in 50 to 70 years and said man would have to replace this metal by another. They said concrete, clay and sand would replace iron in building, industry and life. However, time marches on, the date set for the exhaustion of the iron reserves should be drawing close, but the geologists are discovering ever new iron deposits. The iron-ore resources in the Soviet Union fully satisfy the needs of industry and there seems to be no end to the discoveries of new iron deposits.

Iron is one of the most important metals in the universe. We see its lines in all cosmic bodies; they sparkle in the atmospheres of the hot stars; we see atoms of iron stormily moving across the solar surface;

Iron mining in the Vysokaya Gora Iron Mine near Nizhny Tagil in the Urals (Sverdlovsk Region)

Pouring steel at a modern metallurgical plant

every year they come falling down on earth in the form of fine cosmic dust and iron meteorites. Large masses of native iron fell in the State of Arizona, in South Africa and in the basin of the Podkamennaya Tunguska (U.S.S.R.). Geophysicists assert that the entire centre of the earth consists of a mass of nickeliferrous iron and that our earth's crust is a scale similar to the glassy slags which run out of a blast-furnace during the smelting of pig iron.

But the enormous reserves of iron found in the cosmos or the deposits contained in the interior of our planet are as yet inaccessible to industry; we are living and working on a thin film of earth, and metallurgy must depend only upon the few hundred metres below the surface from which modern mining is able to extract iron ores.

Meanwhile geochemists reveal the history of iron. They say that even the earth's crust contains 4.5 per cent iron and that the only metal of which there is more than iron in surrounding nature is aluminium. We know that it is a constituent of the molten masses

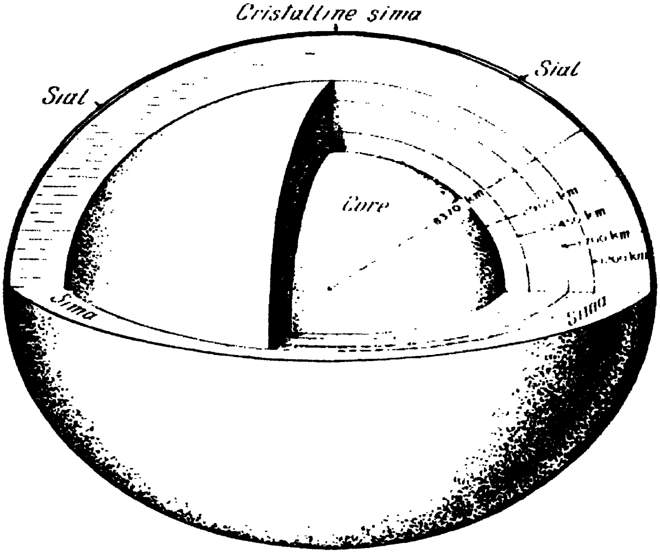


Diagram of the structure of the earth. Sial rocks rich in silicon and aluminium (granite type). Sima rocks rich in silicon, magnesium, and iron (basalt type). The ore shell and the iron core are located in the centre of the earth

which harden in the interior of the earth in the form of olivinic and basalt rocks, as the heaviest and primordial rock (sima).

We know that relatively little iron remains in granite rocks (sial) which is evident from their light colours white, pink and green. And still, complex chemical reactions accumulate enormous reserves of iron ore on the surface of the earth. Some of them are formed in the subtropics where the periods of tropical rains are followed by bright sunny days of hot summers. Everything soluble there is washed out of the rock and large accumulations crusts of iron and aluminium ores are formed.

We know how rushing waters containing organic substance bring tremendous amounts of iron from various rocks and deposit them on the floors of northern lakes, for example in Karelia; pieces of iron as small as pin-heads or whole layers of it are deposited on the floors of the lakes into which the waters flow, involving special iron bacteria. Iron ores have thus accumulated in marshes and on the bottom of seas all through the long geological history of the earth, and there is no doubt that in a number of cases animal and plant life has exerted its influence on the formation of these deposits.

This is the way the large Kerch deposits were formed; the enormous reserves of iron ores in Krivoi Rog and in the Kursk Magnetic Anomaly were, in all probability, also formed similarly.

Old engraving dating from 1497. Magnetic iron cliffs pull the nails out of the ship, and the ship sinks

The ores of these two last deposits were formed by the waters of ancient seas so long ago that the hot breath of the earth's interior has been able to change their structure, and instead of the brown hematite we find in Kerch, we see here altered black iron ores consisting of hematite and magnetite.

The migrations of iron on the earth's surface never cease. True, very little of it accumulates in sea-water and it is rightly said that this water contains practically no iron at all. However, under special, exceptional conditions ferruginous sediments, even entire iron-ore deposits, which are encountered in a number of ancient sea layers, are formed in the sea and in shallow bays. Our famous iron-ore deposits near Khoper and Kerch in the Ukraine and near Ayaty in the Urals were thus formed. But iron is migrating everywhere—in streams, rivers, lakes and marshes—and plants always find this important chemical element without which they cannot live.

Try and deprive a pot of flowers of its iron and you will soon see that the flowers lose their colours and odour, and that their leaves turn yellow and begin to wither away. The life-giving chlorophyll, which imparts the power to the living cell and which extracts the carbon from carbon dioxide by giving up the oxygen to the air, cannot exist without iron because it cannot be formed without it.

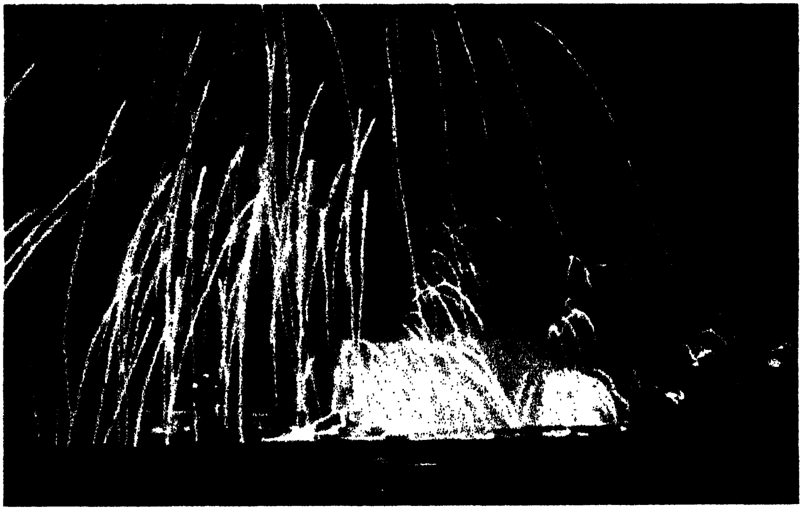
The cycle of iron on earth is, thus, completed in plants and in other living systems, and the red corpuscles in the blood of man are one of the last stages in the migrations of this metal without which there can be no life.

STRONTIUM—METAL OF RED LIGHTS

Sr 38
87.63

Is there anyone who has never seen beautiful fireworks with their red sparks which slowly fade in the air and are replaced by similarly brilliant green lights?

Thousands of bright red, green, yellow and white lights, revolving suns and hissing rockets of the fireworks let off during our major holidays, play in the air and scatter the darkness of the night. Similar



Salute in Leningrad

red flares go up in the air from ships at times of grave danger; they are dropped from planes for night signalization and they talk with each other in their coded language during preparations for night attacks and bombings.

Very few people know how these bright "Bengal" lights, which have got their name from India, are made; there, while conducting religious services, the priests inspired fear in the worshippers by suddenly lighting mysterious ghastly-green or blood-red lights in the semi-darkness of their temples and houses of prayer.

Not everybody knows that these lights are obtained from the salts of strontium and barium, the two peculiar heavy earths that could not be told apart for a long time until it was observed that in fire one of them shed a bright red light and the other a greenish-yellow. Soon afterwards man learned to produce volatile salts of these two metals, mix them with potassium chlorate, coal and sulphur, and from this mixture to press little balls, cylinders and pyramids with which the sky-rockets and the tubes of the fireworks are filled.

Such is one of the last pages in the long and intricate history of these two elements. I should probably bore you if I told you in detail about the long route travelled by the atoms of strontium and barium from the molten granites and alkaline magmas in the earth's crust all the way to the industrial enterprises which refine sugar, produce defence equipment, make metal or manufacture fireworks.

I must tell you that I read a remarkable story about the minerals of strontium written by a Kazan scientist and published in a Volga newspaper while I was still a student of Moscow University. This talented mineralogist described how he and one of his friends collected beautiful blue crystals of celestite on the banks of the Volga. He related how dispersed atoms gave rise to these blue crystals in the Permian limestone, what properties they had and what their uses were; this story imprinted itself upon my memory so vividly that I remembered for many long years the blue mineral celestite which had got its name from the Latin word *caelum*, meaning sky, for its beautiful sky-blue colour.

To find this stone was my cherished dream for a long time; in 1938 I was, finally, lucky enough to find it when I least expected it and I recalled this remarkable story.

I was convalescing in Kislovodsk (North Caucasus). After my serious illness I was still unable to climb mountains though I was irresistibly drawn to rocks, quarries and cliffs.

A beautiful building of a new holiday home was being erected near our sanatorium. It was being decorated by pink volcanic tuff brought from the village of Artik (Armenia) and, therefore, named Artik tuff. The fence and gateway were being made of a yellowish dolomite in which lovely patterns and ornaments were hewn.

I fell into the habit of visiting the building and watching the workmen skilfully hew the soft dolomite stone and knock off separate hard pieces. "In this stone we sometimes find harmful hard nodules," said one of the workers. "We call them stone disease because they get in the way of hewing; we break them off and throw them into that pile there."

I went over to the pile and in one of the broken nodules saw a small blue crystal; why, that was real celestite! It was a lovely transparent blue needle, like a light sapphire from Ceylon, like a light sun-faded cornflower.

I borrowed a hammer from one of the workers, broke up several nodules and was struck dumb with delight. Before me were crystals of celestite. Blue brushes of them lined the cavities inside the nodules. Among them were white transparent crystals of calcite, while the nodule itself was formed by quartz and grey chalcedony, a dense and strong setting for the celestite necklace.

I asked the workers where the dolomite for the building was quarried and was shown the way to the quarry. Early in the morning two days later we drove along a dusty road to the dolomite quarry. Our route ran along the stormy little Alikonovka River, past the beautiful building of the "Castle of Love and Perfidy." The valley grew narrow and changed to a gorge with steep cliffs of limestone and dolomites hanging like cornices over our heads. Soon we perceived the quarry with enormous boulders and fragments of lateral rock.

We had no luck at first. The large nodules, we spared no effort to break up, contained small crystals of calcite and rock crystal or stalagmitic masses of white and grey opal and semi-transparent chalcedony; finally, we hit the right place. One after another we sorted out ores of bright-blue celestite, carefully carried them down, wrapped them in paper and again crawled over the dumps collecting the wonderful samples. Proudly we brought our samples back to the sanatorium, arranged and washed them, but felt we did not have enough. In a few days we were off in our little cart again in quest of celestite.

Our room was filled with boulders of dolomite containing blue eyes; the director of the sanatorium watched us reproachfully, but we kept bringing ever new samples. Our behaviour intrigued some of our sanatorium neighbours. Everybody took an interest in the blue stones; some of them even followed us to the dolomite quarry and also brought back very good samples just to make us envious. But nobody could understand what we collected those stones for.

One very dull autumn evening some of our fellow-patients at the sanatorium asked me to tell them about these blue stones, why they were formed in the yellow Kislovodsk dolomite and what good they were. We gathered in a cozy room, I spread the samples before my listeners and somewhat embarrassed by this unexpected audience, in which many had no knowledge of either chemistry or mineralogy, began my story.

. . . Way back, many, many millions of years ago, the Upper Jurassic Sea rolled its waves to the mighty Caucasian Mountains. The sea now receded and now again inundated the shores, eroded the granite cliffs and deposited along the shores the fine red sand which now covers the paths near the sanatorium.

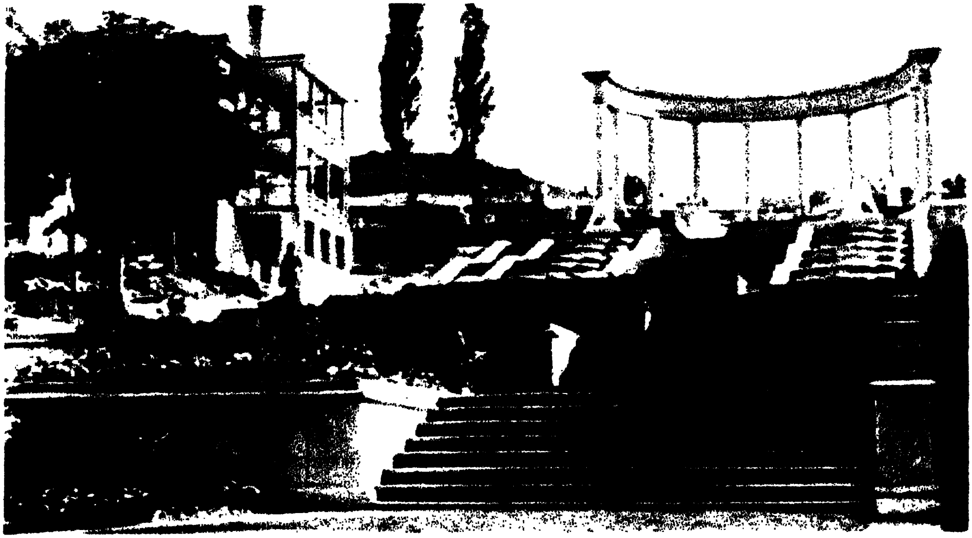
Large salt-lakes were formed in the shallow bays and in the stormy overflowing rivers running down from the mountain peaks of the primeval Caucasus. The Jurassic Sea receded to the north while argillaceous sediments, sands, thin layers of gypsum and in some places rock salt were deposited along the shores and on the floors of lakes, firths and shallow seas.

Continuous layers of dolomite were deposited in deeper places. These dolomites now form heavy strata of uniform yellow, grey and white colour.

But how intricate and varied was the fate of this sea, in which these sediments were deposited! Numerous living creatures swarmed along its shores. Here we could have admired the variegated picture of life which amazes us on the cliffs of the Mediterranean coast and even in the warm bays of the Kola Fiord.

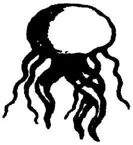
Various blue-green and purple seaweeds, hermit crabs with their beautiful shells, snails and shells of all possible forms and colour

Sanatorium of the Ministry of the Coal Industry in Kislovodsk. Built of local dolomite



Dolomite staircase in Kislovodsk. North Caucasus inhabited these cliffs, covering them with a particoloured carpet. Sea-urchins with their red quills, large five-pointed stars with sinuous points and jelly-fish of most diverse forms gleamed in the water.

Innumerable small radiolarians lived on stones on the floor of the sea near the coastline; some of them were transparent as glass and consisted of pure opal, others were small white globules no larger than one milimetre with a small stem three times the size of the body. They were perched on stones, on beautiful overgrowths of sea mosses and sometimes even covered the quills of sea-urchins travelling with them along the bottom of the sea.



These were the famous radiolarians-acantharia, whose skeletons were made of from 18 to 32 needles. For a long time nobody knew what they were made of and it was only accidentally discovered that they were not made of silica or opal, but strontium sulphate. These innumerable radiolarians accumulated in their intricate life's process strontium sulphate, which they extracted from the sea-water, and gradually built their crystalline needles.

The dead radiolarians fell to the bottom of the sea. Thus began the accumulation of one of the rare metals which got into the littoral waters of the Caucasian seas from the eroded granite massifs, from the white feldspars that form part of the Caucasian granites.

We should probably never have thought of the existence of these acantharia in the Upper Jurassic Seas and it would never have occurred to chemists to look for strontium in the pure limestones and dolomites of our quarries if another event had not disturbed the calm of the old sediments in the Jurassic Seas in those distant times of the geological past.

The Caucasus began to experience new paroxysms of its volcanic activity. Molten masses were erupted again, formation of new mountain ranges was started, hot vapours and springs began to pour out to the surface through cracks and breaks, while the famous laccoliths, the Beshtau, Zheleznaya, Mashuk and other mountains, were coming into being raising layers of Cretaceous and Tertiary rocks in the region of Mineralniye Vody.

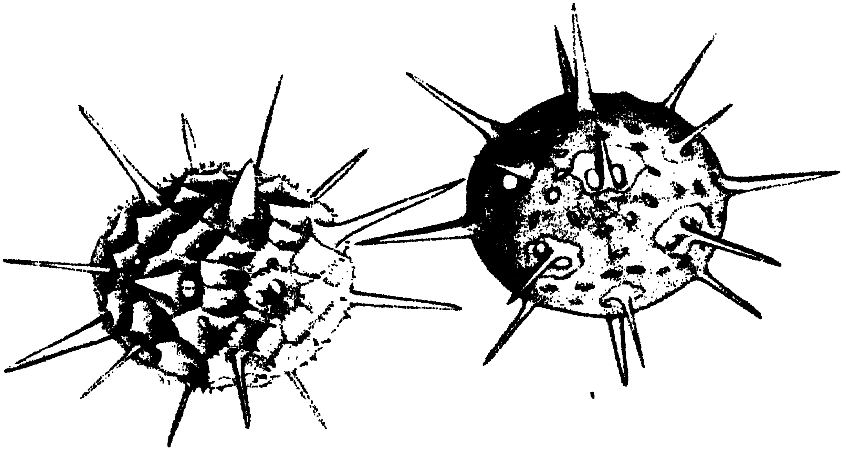
The hot breath of the earth's interior saturated the limestones and the sediments of gypsum and salts, and the latter formed whole underground seas and rivers of mineral waters; sometimes they were cold and sometimes they were still kept warm by the breath of the earth;

these waters pierced the dolomites and limestones in the old sediments along the cracks and by their chemical solutions forced them to recrystallize and change to the beautiful and durable dolomite stone of which houses are built.

Under the influence of complex chemical reactions the minutest dispersed atoms of strontium, the remains of the radiolarians-acantharia entered the solution and were again precipitated in the cavities of the Jurassic dolomites growing into beautiful crystals of blue celestite.

Our celestite geodes were gradually formed over a period of many thousands of years and now, when cold solutions of the earth's surface penetrate to them, the crystals of celestite fade, become opaque, their shiny facets are corroded and the atoms of strontium resume their migrations over the earth's surface in quest of new and stabler chemical compounds.

The picture from the history of Kislovodsk celestites I have just painted recurs in many regions of the country. Wherever large sea basins disappeared and shallow seas and salt-lakes were formed during the history of the earth's crust the little globules of the acantharia died and over a period of scores of millions of years the small needles of the formerly living acantharia gave rise to small crystals of strontium.



Skeletons of protozoa acantharia, whose needles consist of strontium sulphate

Geode of celestite split in two parts

The mountain ranges in Central Asia are engirded by an unbroken ring of celestite rock; we picture to ourselves similar crystals in the most ancient Silurian seas in the Yakutian Republic, but the largest deposits are connected with the seas of the Permian epoch which deposited tremendous amounts of celestite in the limestones along the Volga and the Northern Dvina.

I shall not tell you what subsequently happens to the crystals of celestite in the earth's crust. Many of them, as we have seen, begin to dissolve again, their atoms get into the soil, are carried away by water, are dissolved in the boundless oceans, are accumulated again in salt-lakes and sea firths, form needles of acantharia again and in millions of years will again give rise to new crystals of celestite.

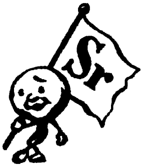
In this continuous change of chemical processes, in the complex chain of natural phenomena the mineralogist and geochemist grasp only separate links. He must penetrate with his experienced eye, fine analysis and profound scientific thought into the complex course of migrations of the atom in the universe. From separate passages he recreates whole pages and from these pages he compiles the great book of the chemistry of the earth which tells us from beginning to end how the atom migrates in nature, who his fellow-travellers are, where it finds its peaceful or restless death in the form of stable crystals, where the dispersed atoms eternally change their fellow-travellers now entering solutions and now endlessly scattering in the great vastness of nature.

And the geochemist must get an insight into these intricate migrations of the atom.

The minutest crystal must lead him like a thread to the beginning of the clew. Are we in a position to speak of the beginning of the history of strontium atoms?

Where and how did they come into being in the history of the universe?

Why do the lines of strontium sparkle particularly brightly in some stars? What are these lines doing in the rays of the sun and how have they come to be there? How has this metal accumulated on the surface of the earth's crust, how has it collected in the molten granite magmas and how has it concentrated together with calcium in the white crystals of feldspars?



All these are questions the geochemist cannot answer. He cannot tell you as clearly about this as I have just told you about the blue crystals of celestite in the environs of Kislovodsk. And he can tell you as little about the last pages in the history of the strontium atom.

Man had long paid no attention to it. He sometimes used it for his red lights, but for that he did not have to extract large quantities of strontium salts from the entrails of the earth. Then some chemist found a happy use for strontium in the sugar-refining industry; he found that strontium and sugar formed a special compound, strontium saccharate, and that this compound could be successfully used in refining sugar from molasses. Extensive utilization of this metal began and large amounts of it were mined in Germany and Britain. But another chemist found that strontium could be replaced by calcium which is cheaper. The strontium method proved unnecessary and the metal began to be neglected, the mines were closed and only here and there were the wastes of its salts used for red lights.

Then came the imperialist war of 1914-18, and enormous quantities of signal flares were needed. Red, fog-piercing lights proved indispensable in lighting the spaces that were to be photographed from the air;

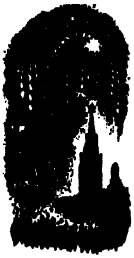
the carbons of the searchlights were impregnated with salts of rare earths and strontium.

A new application was found for strontium.

Later metallurgists learned to produce metallic strontium. Chemists, metallurgists and manufacturers took a new interest in strontium. Like metallic calcium and barium it purifies iron from harmful gases and admixtures.

It began to be used in ferrous metallurgy, and now geochemists are searching for its deposits again, are studying the accumulations of strontium in the caves of Central Asia, are producing its salts at large plants and are extracting it from mineral waters; in a word, strontium has again become an element of industry. We cannot tell its future fate. We, geochemists, do not yet know either the first or the last pages in the history of this metal....

That was how I finished my story about the blue stone to my listeners at the sanatorium.



In their eyes the useless blue crystals were transformed into a part of socialist construction. They no longer looked askance at our morning trips to the quarry, and even the chief surgeon ceased grumbling that we filled the whole room with stones and were violating the sacred sanatorium regimen. In a word, celestite helped us to make up again.

It was then that I decided to write my story about it. It appears in my book entitled *Recollections about a Stone.*

I advise those of you who were not bored by this essay to read also that little story in order that you better remember what a fine stone our blue celestite is.

TIN —METAL OF THE FOOD-CAN

Sn 50
118,70

Tin is a modest and seemingly in no way distinguished metal. We very seldom hear of it in our everyday life though we use it very often. The fate of this metal is to serve man under a different name.

Bronze, white metal, solder, babbitt, printer's stone, artillery metal, tin-foil, beautiful porcelain enamels, paints and the like are some of the different and useful things of which many people would never think tin forms the most essential constituent.

This metal is notable for its remarkable and very singular properties: some of them are still a mystery and are not yet fully understood by geochemists.

The granite magma which rises from the interior of the earth and is rich in silica (and as it is customarily called "acid") is the source of tin. However, tin is far from being found in every acid magma, and we do not know yet what law governs the bonds of tin with granite, why it is found in one granite and why there is hardly any trace of it in another, seemingly the same, granite.

Another interesting question is: why does not tin, a heavy metal, sink in the magma like other heavy metals, because of its gravity, but tends to come up and is found in the uppermost layers of the granite massif?

The thing is that among the vigorous highly volatile vapours and gases dissolved in the magma the halogens, chlorine and fluorine, play an important part. We know from experience that tin combines with these gases even at room temperature. In the magma it forms very volatile compounds with these gases tin chlorides and tin fluorides. And in this gaseous state tin together with other volatile

Pegmatite veins with tinstone in granites. Turkestan Mountains

those of silicon, sodium, lithium, beryllium, boron and others, makes its way to the upper zone of the granite massif and even beyond it into the cracks in the surface rocks.

Here under different physico-chemical conditions the tin chloride and tin fluoride react with water vapours. Leaving its former carriers tin combines with the oxygen it takes up from the water and is now no longer liberated in the gaseous state, but in the form of a hard, shiny mineral called cassiterite or tinstone, which is the principal industrial tin ore. Many other interesting minerals are sometimes liberated together with cassiterite; these include topaz, smoky quartz, beryl, fluor-spar, tourmaline, wolframite, molybdenite, etc.

We found out quite recently that large deposits of cassiterite are formed not only from volatile haloid compounds of the granite magma.

They also arise at later periods in the hardening of the granite residue when the water vapours are transformed into liquid water which transports compounds of various metals far away from the maternal centre; these compounds are mostly sulphides—sulphur compounds. There is a good deal in these processes we do not understand as yet, but we do know that tin is carried out of the magma also in this manner. It is remarkable that having used sulphur as a carrier this time tin abandons it as it formerly did the halogens and combines with oxygen again forming its favourite mineral—cassiterite.

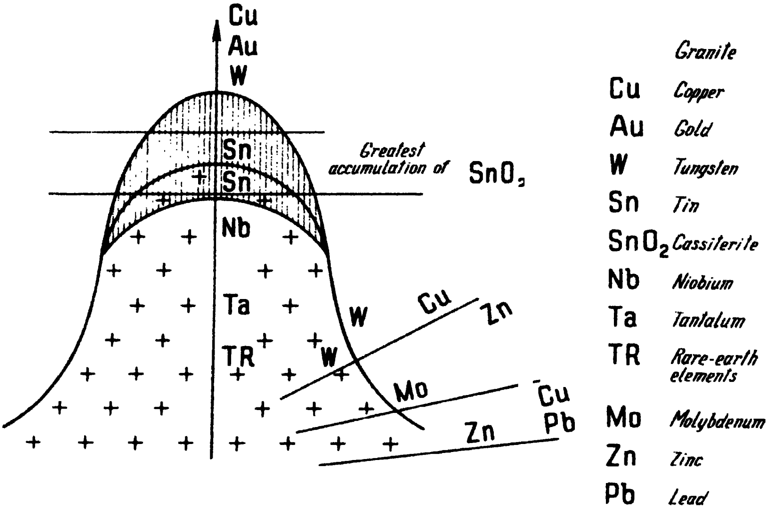


Diagram of distribution of tin and its fellow-travellers in the upper part of a granite massif

We know that tin also forms part of many other minerals, but all of these are very rarely encountered (some—exceptionally rarely) and are of no industrial importance. Cassiterite, SnO_2, which contains about 78.5 per cent pure tin, has always been the only tin ore.

Cassiterite (from the Greek word *cassiteros*—tin) is mainly a black or brownish mineral. Its black colour is explained by admixtures of iron and manganese. It is rarely honey-yellow or red and still more rarely colourless. Its crystals are usually very small. Because of its hardness, chemical stability and gravity cassiterite does not disintegrate and is not dispersed during weathering, but accumulates with other heavy minerals on the sites of granite destruction, i.e., in river-beds or on sea coast, sometimes forming vast placer deposits of tinstone.

Cassiterite is, thus, obtained from primary and secondary deposits.

Whatever way the tin ore is obtained, first of all it goes through a process of concentration, i.e., it is purified from various admixtures, after which it is smelted. At this time the tin is reduced by the carbon of the fuel. Combining with carbon oxygen is liberated as carbon dioxide, while pure metallic tin remains.

Working a tin vein at Llallagua, Bolivia, at an altitude of 4.500 metres above sea level (1940)

Pure tin smelted from cassiterite is a soft, silvery-white (a little duller than silver) malleable metal. The capacity of tin to be rolled into thin sheets is remarkable. Tin melts at 231° C.

Tin has very many peculiar properties. It is known to be able to yell, i.e., to produce a special characteristic sound when bent. Another singular, though far from indifferent, feature of this metal is its sensitivity to cold. Out in the cold tin takes *sick*: from silvery-white it turns grey, increases in volume, begins to crumble and not infrequently breaks up into a powder. This is a serious disease and it is called "tin plague." This disease has ruined many a tin object of great artistic and historical value. Sick tin may infect healthy metal. Fortunately tin plague can be cured. The metal must be resmelted and slowly cooled. If this operation (especially cooling) is performed sufficiently thoroughly tin resumes its former appearance and properties.

In the very distant past it was precisely tin that gave a powerful impetus to the cultural development of man. Man has known tin for

Field of tin-bearing sands on Malacca Peninsula. Washed by hydromonitor (water gun). Washed mud flows along ditches. Johore Bahru Mine (1940)

a very long time and was able to smelt it five or six thousand years B.C., i.e., long before he learned to smelt and process iron.

Pure tin is a soft and weak metal, and is unfit for manufacture. But "bronze" (from the Persian word *brontpsion*, meaning alloy), a gold-coloured alloy consisting of copper and 10 per cent tin, is known for its fine properties: it is harder than copper, is easily cast, forged and processed. If we designate the hardness of tin by the conventional number of 5, copper will have a hardness of 30, while bronze, an alloy with a small amount of tin, will have a hardness of 100 to 150. Because of these qualities bronze was so widespread in its time that archaeologists even distinguish a special epoch—the Bronze Age—when work-tools, arms, housewares and decorations were made mainly of bronze. How man discovered this remarkable alloy we do not know. It is possible that man repeatedly smelted copper ore with an admixture of tin (we do encounter such "complex" deposits of copper and tin), finally noticed the result of this joint smelting and grasped its significance.

During excavations of ancient settlements archaeologists very frequently find well-preserved bronze-wares—household utensils, coins and statuettes. If it is necessary to know whether these bronze-wares are local or imported a chemical analysis of the objects can provide valuable information.

Chinese boy washing tin-bearing sands in a ditch. Malayan Archipelago

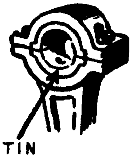
Ancient metal was very imperfectly refined, and by modern exact methods of analysis we can detect in it many different elements in the form of insignificant admixtures impurities. The composition of these impurities sometimes offers a clew to the deposits where the copper and tin used in this bronze were obtained. If the historian or archaeologist definitely prove that the found bronze articles were manufactured where they were found the geologist and the geochemist must immediately start looking for tin in that region. It is possible in this way to rediscover long forgotten tin deposits.

But bronze did not lose its importance even when the Bronze Age was replaced by the Iron Age. Man used it for objects of art, for minting coins and for casting church-bells and cannon.

Tin can also form remarkable alloys with other metals, for example, with lead, antimony, etc.

In our time alloys are a sphere of technical wonders, a world of "magic" transformations. Soviet scientists have come to know and interpret these "wonderful" phenomena, these regroupings of atoms which occur when two or more metals are alloyed. Owing to the changes in molecular structure the alloy acquires new properties alien to each of the metals taken separately. For example, an alloy of soft metals often unexpectedly becomes very hard.

Alloys of tin and lead, so-called *babbitts*, are used in powerful and precision apparatus and in machinery, wherever the action of a steel rod revolving at an enormous speed must be rendered harmless. These so-called "antifriction" alloys are very durable (they are said to have



a low friction coefficient). They are very important technically because they prolong the life of costly machinery.

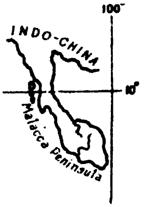
Tin possesses the remarkable capacity for being welded to metals; the use of the so-called solders, i.e., alloys of tin with lead and antimony, in engineering is based on this property.

Not everybody knows what tin means to printing. It is the principal component of the so-called "type metal" of which *clichés*, i.e., forms with relief drawings to reproduce illustrations, are cast.

Nothing in the world imparts that mirror-like lustre to beautiful white and coloured marbles in polishing as does the white tin-oxide powder.

Various tin compounds are widely used in the chemical and rubber industries, in print works, in dyeing wool and silk, in the manufacture of enamels, glazes, stained glass, gold and silver leaf. It also plays a very important part in warfare.

The oldest tin deposits have been known in Asia and in Europe, in the south of the British Isles which were even called "Cassiterides." It is hard to say, though, whether cassiterite got its name from the isles or the isles were named after the Greek word "cassiteros" which we encounter in Homer's *Iliad* where it is used to signify tin. It is noteworthy that in Cornwall cassiterite is found together with chalcopyrite, a copper mineral, so that when smelted this ore at once produces bronze.



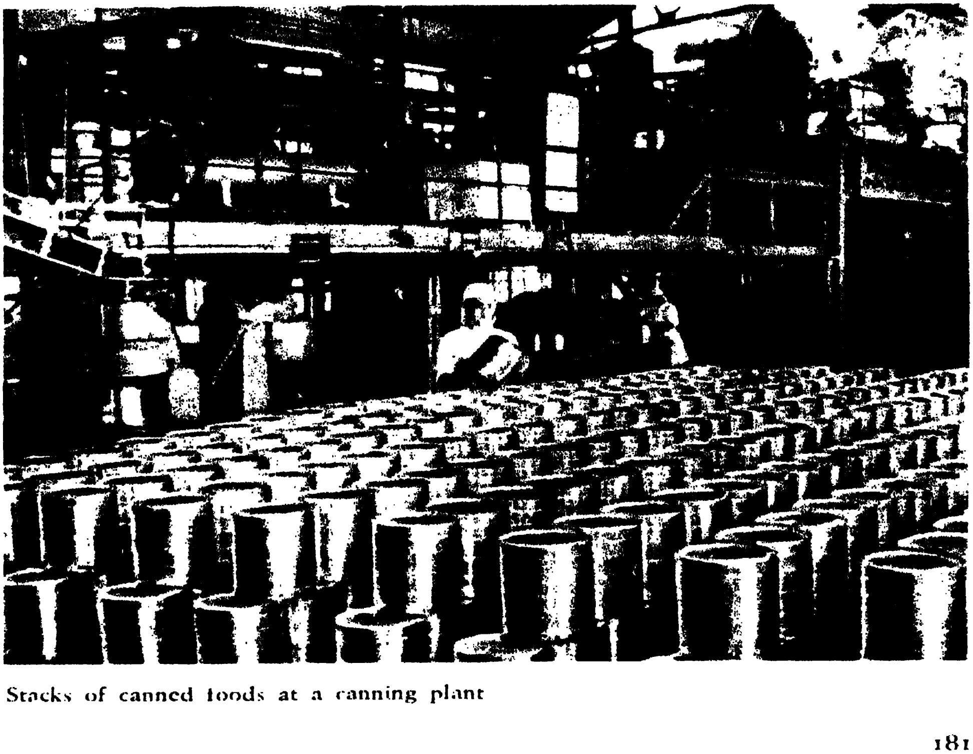
The main source of tin today is Malacca Peninsula, which yields close to half the world's output of this metal, and where more than 200 deposits in granites and a vast number of rich placer deposits are known. The placer deposits are worked hydraulically; they are washed by powerful streams of water discharged from monitors. Liquid mud composed of a mixture of different minerals flows into special ditches with riffles where it is vigorously stirred by workers from the local population. This hard work is done mainly by children. Owing to its high specific gravity cassiterite is retained by the riffles, whence it is removed from time to time. The method of production, as you see, is very primitive and is based on cruel exploitation.

The concentrate containing 60 to 70 per cent cassiterite is transported to plants where it is smelted for tin.

The imperialist countries have been waging a fierce struggle for tin. During the Second World War Japan strove to take possession of the tin deposits on the continent and on the islands, and the tin-smelting plants in Singapore owned by British firms in order to provide for the needs of her war industry and to help Hitler Germany which was very short of tin. Japan and Germany at the same time aimed at depriving the U.S.A. and Britain of the sources of this valuable war metal.

Take a look at the world map and you will see that the zone of tin-bearing granites and, hence, tin deposits, as well as those of tungsten and bismuth, runs along the Pacific Coast, through the Billiton (or Belitoeng), Banka (Bangka) and Singkep islands, Malacca and Thai peninsulas and South China.

Geochemistry is striving to divine the reasons for the formation of these zones containing rich deposits of tin ores and other chemical compounds found together with tin.



Stacks of canned foods at a canning plant

In addition to Malacca there are very rich tin concentrations in Bolivia (South America). They are located in the Cordilleras. Lesser deposits are known in Australia, Tasmania and in the Belgian Congo (Africa).

Of the nearly 200,000 tons of tin constituting the world's annual production 40 to 50 per cent is used in the manufacture of white metal.

Consumption of white metal is sharply increasing with the development of the canning industry.

Have you ever thought of the importance of *white metal* and of the part played by the tin can in which millions of kilograms of meat, fish, vegetables and fruit are preserved? What is white metal? It is sheet iron covered with a very thin layer of tin about 0.01 mm. thick. Tin plating or tinning of the iron sheets or iron cans prevents them from rusting. Pure tin is not dissolved by the liquids of the canned foods and is practically harmless to man's health. No other plating can compete with tin in stability.

Today we can say that tin has outlived its "bronze age" and has become a metal of the food-can.

IODINE THE OMNIPRESENT

I 53
126.92

We all very well know what iodine is; we use it externally when we cut a finger and take its brown-red drops with milk when we grow old. Iodine is a well-known drug and yet how little we really know about it and about its fate in nature!

It would be hard to find another element as full of contradictions and riddles as iodine. Moreover, we know so little about the principal milestones in the history of its migrations that we cannot say as yet why we use it as a medicine and where it has come from?

It will be observed that even D. Mendeleyev ran into the unpleasant properties of iodine. He distributed his elements in the order of increasing atomic weights but iodine and tellurium upset the order: tellurium stands before iodine though its atomic weight is higher. It is still that way today.

Iodine and tellurium were nearly the only elements that disturbed the harmony of Mendeleyev's Law. True, we have an idea of what is what today, but for many years this was an incomprehensible exception; the critics of Mendeleyev's brilliant theory repeatedly indicated that he placed his elements as he saw fit.

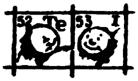
Iodine is solid; it forms grey crystals with a real metallic lustre. It looks like a metal and it is shot with violet, but at the same time if we put the metallic iodine crystals into a glass phial we soon see violet vapours in the upper part of the phial; iodine is easily sublimated without passing through the liquid state.

Here is the first contradiction that strikes your eye, but this is immediately followed by another. The colour of the vapours is dark violet, while that of the iodine itself is metallic grey. The salts of iodine

Mountain ranges of the Central Pamirs. Picture made during ascent to Mount Stalin from an altitude of 6,500 metres

are altogether colourless and look like common salt; only some of them have a slightly yellowish tint.

And here are some other iodine riddles. Iodine is an exceptionally rare element; our geochemists have estimated that the earth's crust contains only about 0.00001 or 0.00002 per cent; nevertheless iodine is found everywhere. We can probably say it even more bluntly: there is not a single thing in our surroundings in which the finest methods of analysis do not, finally, detect a few atoms of iodine.



Everything is permeated with iodine: the solid earth and rocks, even the purest crystals of transparent rock crystal or Iceland spar contain quite a number of iodine atoms. Sea-water contains much more of it, the soils and running waters contain very much, and plants, animals and man contain still more. We absorb iodine from the air which is saturated with its vapours; we consume it with food and water. We cannot live without iodine. Now we can understand the questions: why does iodine exist everywhere? Where does so much iodine come from? Which is its primary source? From what depths of the earth's interior is this rare element brought to us?

You find me all over!
I

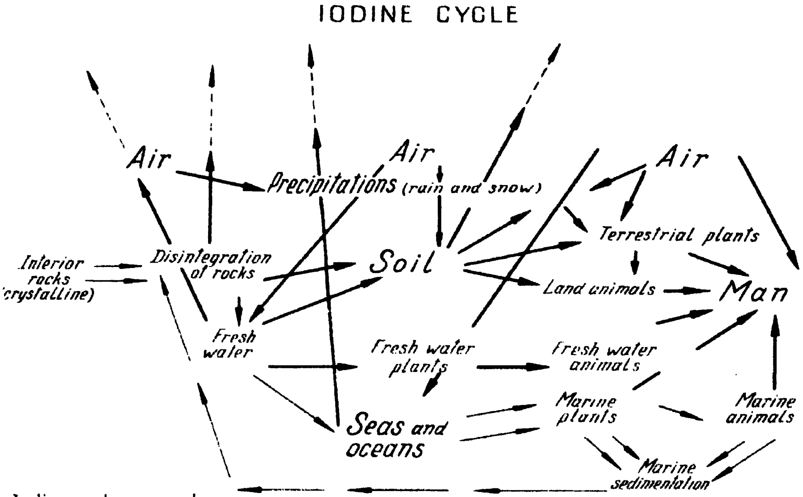
Meanwhile even the most precise analyses and observations fail to discover its mysterious source because we do not know a single iodine mineral either in deep igneous rocks or in the molten magmas that have come to the surface. Geochemists picture the origin of iodine on earth as follows: at one time, before the geological history of the earth, when our planet was beginning to be covered with a hard crust, continuous clouds of volatile vapours of various substances enveloped the still hot earth. It was at that time that iodine and chlorine were released from the depths of the molten magmas of our planet and iodine was seized by the first streams of the precipitated hot water vapours, and the first oceans, which gave rise to seas, accumulated iodine from the atmosphere of the earth.

We do not exactly know if this was really so, but we do know that its distribution on the earth's surface is replete with riddles. In the Arctic countries and in high mountains there is comparatively less iodine; in the lowlands and near seashores the content of iodine in the rocks increases; it increases even more in deserts while in the salts of the large deserts in South Africa or in the Atacama Desert (South America) we find real mineral compounds of iodine.

Iodine is dissolved in the air; accurate analysis has shown that it is distributed in the air according to a very definite law: its amount varies with the altitude. At the altitudes of the Pamirs and the Altai, more than 4,000 metres above sea level, there is much less iodine than at the level of Moscow or Kazan.

At the same time we know that iodine exists not only on the earth. We find it in meteorites which come to us from unknown spaces of the universe. Scientists have long been looking for it with the aid of new methods in the atmospheres of the sun and stars, but so far to no avail.

Sea-water contains quite a lot of iodine – about two milligrams per litre, which is already an appreciable quantity. Sea-water condenses near the shores, in firths and in littoral lakes where salts accumulate and cover the flat shores with a white film. These salt concentrations have been very well studied on the Crimean Black-Sea coast and in the lakes of Central Asia, but no iodine has been found in them; it has disappeared somewhere. Some part of the iodine, apparently, accumulates in silts on the bottom, but the greater part of it evaporates, goes up into the air, and only a small portion of it is retained in the



Iodine cycle on earth

residual brines. But hardly any iodine is found where the salts of potassium and bromine are accumulated.

Vegetation sometimes develops near the shores of salt-lakes and seas, forming whole forests of seaweeds which cover the littoral stones. It is in these seaweeds that iodine accumulates as a result of some incomprehensible biochemical processes, and each ton of seaweeds contains several kilograms of pure iodine, this remarkable element. Certain sea-sponges contain even more iodine, i.e., up to 8 or 10 per cent.

Soviet investigators have made a particularly good study of the Pacific coast. Along the entire vast coast the waves bring, mainly in autumn, a tremendous quantity (over 300,000 tons) of sea-kale. These brown seaweeds contain many hundreds of thousands of kilograms of iodine. They are collected, partly used for food and partly carefully burned to extract iodine and potash from them.

But the history of iodine in the earth's crust does not end with that. Iodine is also brought by oil waters. Lakes of waste waters from which iodine is now extracted are formed near Baku.

It is also extruded by some volcanoes from their mysterious entrails.

The fates of this element in the history of our earth are so diverse that it is hard to paint a full and coherent picture of the life and wanderings of this incessantly migrating atom.

Then iodine gets into the hands of man and a new riddle arises: we treat sick people with iodine, stop haemorrhages with it, kill bacteria, prevent the infection of wounds, but for all that iodine is exceptionally poisonous: its vapours irritate the mucous membrane. Too many drops or crystals of iodine can prove fatal to man. But the most surprising thing is that man is worse off when there is too little iodine. The organism of man and, probably, of a number of animals must have a definite amount of iodine. We know that iodine deficiency in some regions manifests itself in a special disease called goitre. This disease usually affects people living in Alpine regions. We know some villages in the high mountains of the Central Caucasus and the Pamirs where this disease is widespread. It is also very well known in the Alps.

American investigators have recently found that goitre is also widespread in America. It appears that if we chart the incidence of goitre and draw up a map of the percentage of iodine contained in the water the data of the two maps will coincide.

The human organism is exceptionally sensitive to iodine, and a decrease in its content in the air and water immediately affects the health of man. Man has learned to treat goitre with salts of iodine.

No less interesting are the ways in which iodine is employed in industry; the latter makes more extensive and more diverse use of iodine with each passing year. On the one hand, man has discovered compounds of iodine with organic substances which create an armour impenetrable by X-rays; at the same time if these compounds are introduced into the organism they make it possible to photograph the internal tissues with especial clarity.

We have learned that iodine has recently found entirely new fields of application. Particular importance is attached to the use of iodine in the celluloid industry where special salts of iodine in the form of small needle-like crystals are employed. These needle-like crystals are so distributed in the celluloid that the waves of a light ray cannot go through them in all directions. The result is what we call a polarized ray. We have long built special, very expensive polarizing microscopes,

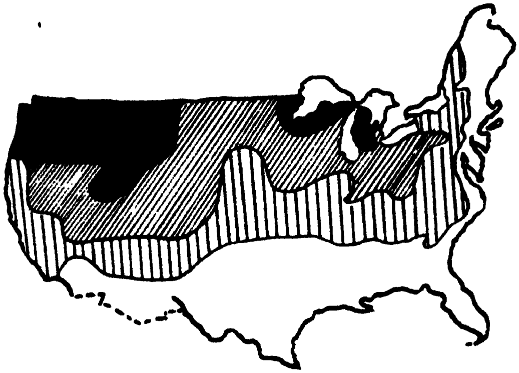
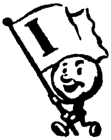


Diagram of the incidence of goitre in the U.S.A. and the iodine content in water; wherever there is little iodine there are many goitre cases. White space shows area in which drinking water contains from 3 to 20 billionths of iodine with 1 goitre case per 1,000 population annually. Straight shaded space shows area where water contains less than 2 to 9 billionths of iodine: goitre went up to 5 cases. Diagonally shaded space shows area in which water contains 0.5 to 2 billionths: goitre 5 to 15 cases. Black space shows area in which water contains 0 to 0.5 billionths of iodine: goitre 15-40 cases per 1,000 population

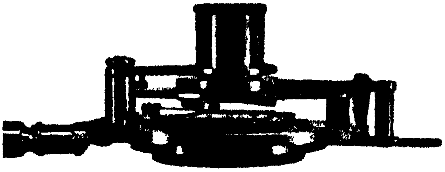
but now this new filter-polaroid has helped us to invent magnifying glasses which have replaced the microscope. They can be used during expeditions in the field. By combining two or three polaroids it is possible to impart very bright colours to the drawing: I can picture to myself a lighted decorative panel or motion-picture screen where two rotating polaroids will produce remarkable picturesque effects rapidly changing all colours of the solar spectrum. When a polaroid plate is put into an automobile's windshield you can drive along a lighted street and the bright headlights of cars will not blind you because in the polaroid you will not see the brilliant haloes of the fiery lights but only the car with a separate luminous point.



When a plane rises above a blacked-out city and drops sparkling compounds of magnesium by parachute polaroid spectacles make it possible to see everything underneath the flare.

You see how extensively and diversely this element is used, how many vague problems and how many contradictions in the fate of its migrations there are. It still requires a lot of profound research to reveal all its properties and to understand the nature of this omnipresent element.

The history of the discovery of this element is also interesting. It was discovered in the ashes of plants in 1811 by Courtois, a pharmaceutist who owned a small factory processing the ashes of plants into saltpetre. However, the discovery of this element did not particularly impress the world's scientists and it was duly appreciated only 100 years later.



Pocket mineralogical magnifying glass with polaroid made of iodine compounds. Designed by Professor V. Arshinov

With this I could finish my story about this interesting element, but one more thought still occupies my mind. There is a vacant box below iodine in the same group in Mendeleyev's table. It was pointed out yet by D. Mendeleyev who said that a new element would have to be found for it; he named it ekaiodine. We call this box No. 85. But where is this element No. 85 found or where is it hiding? It must exist somewhere in the world and it must be discovered.

It was long searched for in residual brines of lakes and salt deposits. It was sought in interplanetary spaces among the dispersed atoms, which are observed in the universe amid the stars and suns, planets and comets; it was also looked for in all natural metals, but was never found.

Many times scientists thought that in their instruments they saw a flash of a line corresponding to the luminescent atoms of No. 85, but subsequent investigations failed to confirm this discovery, and box No. 85 is vacant to-date.*

What is this mysterious undiscovered atom? It probably continues the puzzling history of iodine; it is likely endowed with even more wonderful properties and it is precisely this that renders its discovery difficult. It may exist in the universe for so short a time that even the most accurate instruments are unable to detect it; it may have so strong a charge that it cannot exist in our world. But if No. 85 is discovered on earth it will prove an even more remarkable element than iodine and will have even more fabulous properties.

It is well worth the scientists' while to work on the riddles of iodine and its fellow-element in the table.

* See the word "astatine" in the dictionary of elements.

FLUORINE THE OMNIVOROUS

F 9
19.00

When I planned this book I intended to write a chapter on fluorine and its remarkable properties, but as I came to it I had to stop. I had never worked with fluorine and its compounds, had never taken an interest in its fine minerals or in its use in industry and was, therefore, in a quandary.

I had to resort to my numerous old notes and poring over them I found a number of pages from which I compiled this chapter.

Charles Darwin points out in his autobiography how a scientist must work. He says that a scientist cannot and does not have to remember everything, that he must make a note of every interesting observation and whatever curious information he finds in books on separate slips of paper, and that he should put every book that deals with questions he is interested in on a separate shelf together with the notes.

Darwin did not think a scientist should have a large and diverse library. He always planned his major problems a few years ahead and fully devoted himself to their solution. For each problem he picked his materials dozens of times, and one or two shelves in his bookcase were occupied by the materials on individual problems.

In several years (and sometimes it took a dozen years), he would, thus, accumulate enormous factual material for each scientific problem. He would look through this material and these books once more and write the corresponding chapter of his famous treatise that has laid the basis for modern biological science.

This idea of compiling big books and monographs is very convenient and I confess that already 20 years ago I began to follow this wonderful

View of southern Trans Baikal regi

example set by Darwin and decided to prepare the books and materials for my works in an exactly similar manner. I presented my large library to the Khibiny Mountain Station on Kola Peninsula and retained only the books that were connected with the tasks I faced in the immediate future.

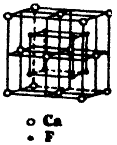
These tasks included a big problem - to write a history of all chemical elements in the earth, to show geologists, mineralogists and chemists the intricate course travelled by the atoms of any metal in their migrations in the universe, and to tell about their properties and behaviour on earth and in the hands of man.

When I came to write the chapter on fluorine I found five small sheets of paper in the paper-case which bore the inscription "Fluorine." I shall give them to you approximately the way they were written.

SHEET 1

I have long since wanted to visit the famous Trans-Baikal deposits whence I received remarkable crystals of topaz, the beautiful rare mineral containing fluorine, crystals of all colours and druses of multicoloured fluor-spar produced for the needs of industry.

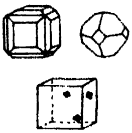
Finally, we got out of the express train which was on its way to the Manchuria Station.



At the station we were met by a troika and we drove down the wonderful steppes in the south of Trans-Baikal region covered with a continuous white carpet of beautiful edelweiss. The enchanting picture opened up ever more widely before us as we climbed the gently sloping hills. Here in separate granite outcrops crystals of blue and yellowish topaz were extracted; here in the cavities of granite pegmatites we saw beautiful octahedrons of fluor-spar -- compounds of fluorine and the metal calcium. But we were particularly impressed by the picture of a rich deposit of this mineral in a certain small valley.

Here they were no longer separate small crystals precipitated from the hot aqueous solutions of cooled granites, but enormous concentrations of pink, violet and white fluor-spar of the most diverse shades; they shone and sparkled in the bright Manchurian sun.

This valuable stone was quarried in order to be sent all across Siberia to the metallurgical plants in the Urals, Moscow and Leningrad. A grand picture of gaseous emanations of ancient and deep molten granites arose before my eyes. Concentrations of fluor-spar were formed from volatile fluorine compounds. One of the stages in the process of slow cooling of the granite massif, surrounded by the vapours and gases it gave off, in the interior of the earth was reflected in these formations.



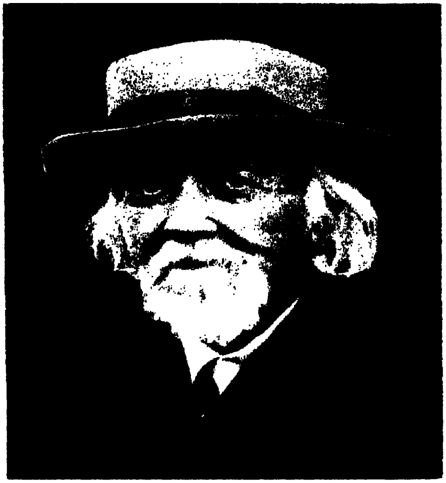
I recalled another picture from the history of the same fluor-spar. The fluor-spar of enchantingly beautiful colours from which the valuable Murino vases were manufactured and which was described in the old mineralogy textbooks came to my mind.

I also recalled that in Britain there was a whole industry for the processing of this stone and that in museums we could see beautiful articles made from it.

Finally, quite different pictures from the environs of Moscow occurred to me.

As a young teacher at the First People's University in Moscow I charged my students with the task of studying the minerals found in the environs of our city. These minerals included a remarkable violet-coloured stone which had been found more than 140 years ago (1810) in the small Ratov ravine, Vereya District, Moscow Region, and had been named ratovkite.

It occurred in individual concentrations in the form of beautiful violet strata amid limestones. Zones of its dark-violet cubes were found along the banks of the Osuga and Vazuzya rivers, tributaries of the Volga. We started actively studying this stone which turned out to be a pure calcium fluoride, the fluorite I am telling you about. Its beautiful violet-coloured pebbles were encountered in such large amounts and the strata were so regularly deposited amid the limestones that it was hard to attribute their formation to the hot emanations of molten granites which had given rise to the lovely Trans-Baikal topazes and the Manchurian fluorspar deposits.


Academician Alexander Karpinsky (1847-1936)

More than 2,000 metres separated these deposits from the ancient granites, which form the basis of Moscow rocks, and we had to look for some other chemical agents that accumulated this beautiful stone along the Volga tributaries. With the aid of Academician A. Karpinsky our young people were able to divine the origin of this stone.

It appears ratovkite was connected with the ancient sediments of the Moscow seas and that in its concentration a part was played by living creatures, i.e., sea-shells, especially the lime-shells that accumulated crystals of calcium fluoride in their cells. The pictures I have painted here clearly show the peculiar and intricate course travelled by fluorine in its migrations in nature.

SHEET 2

A brief description of one day spent in Copenhagen, the Danish capital, during my trip to a geological congress.

After the congress we visited the famous cryolite mill in the environs of this city. The snow-white stone resembling ice is brought here from peaks on the icy coast of Greenland. Due to some strange natural coincidence this stone, in no way differing in appearance from ice, is encountered only in one place on earth—in the polar regions of the west coast of Greenland where it is quarried in vast fields, loaded on ships and sent to Copenhagen. Cryolite goes to special mills where it is separated from the other minerals, especially lead, zinc and iron ores, and only a pure snow-like powder remains and is used as flux for the production of aluminium.

Highly valuable, this powder is shipped in special boxes to chemical plants where a new fate awaits it: it is smelted together with aluminium ore in electric furnaces and the stream of molten metal glitter-

Tajiks examining ore containing crystals of fluorite from a deposit in Tajikistan

Professor Moissan obtaining the first fluorine in his Paris laboratory in 1886

ing like silver runs down into large tanks prepared beforehand. This metal is aluminium and modern aluminium production cannot do without cryolite.

So far there are no other methods of producing this metal which is necessary for the industries of both war and peace and the annual world output of which now runs into two million tons.

Enormous electric installations use the power of large rivers and waterfalls to dissolve aluminium oxide in cryolite and to produce pure metallic aluminium. True natural cryolite is now replaced by an artificial salt of aluminium and sodium fluoride. But it is the same cryolite only produced by man at chemical plants.

SHEET 3

Fragments of pure transparent fluorite were found on the steep slope of a cliff overhanging a beautiful lake in Tajikistan. It was so transparent that lenses for microscopes and precision instruments

At Lake Iskander-Kul, Tajik S.S.R. Left—"Stone Mushrooms"—result of rock weathering

could be made from it. The demand for transparent fluorite was so great that it was necessary to send a special expedition to the steep cliffs bordering the lake.* In the reports of the expedition we read with keen interest about the unusual difficulties of extracting the transparent white fluorite imbedded in dense limestones.

It took a lot of hard work to break small paths to the deposit overhanging the lake. But it was still harder to bring separate valuable pieces of the minerals down to the village located on the shores of this lake. Passing large boulders of this rare stone from hand to hand in a chain Tajik mountaineers brought them down, packed them in soft grass, crated them and delivered them to Samarkand on pack animals.** The optic instrument industry obtained exceptionally pure fluorite and was able to manufacture fine, pure lenses and to build some of the world's best optic instruments from this mineral.

SHEET 4

While taking a course of treatments at a Czechoslovak health resort we were asked to visit a glass-works located in the environs of the city; the works was equipped according to the last word of engineering.

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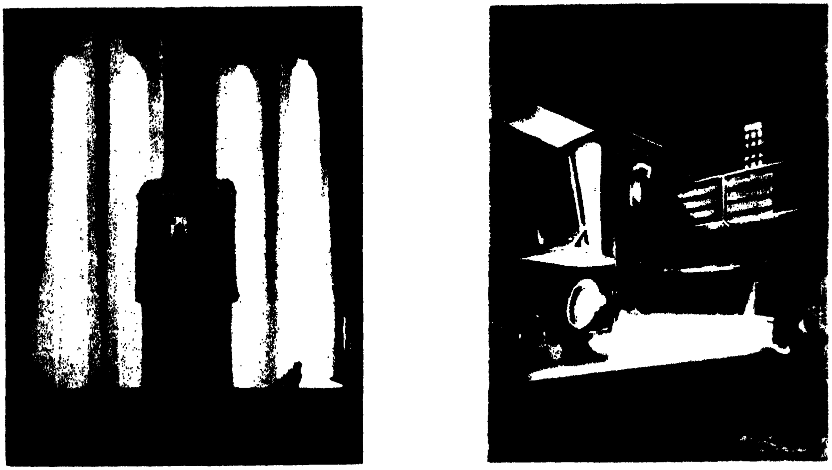
* Tajiks call fluorite "sang i-safet"—"white stone." The deposit was found by a shepherd-boy, named Nazar-Ali, in 1928.

** Optic fluorite is an extraordinarily delicate mineral: it can be spoiled not only by shocks and blows but even by sharp changes in temperature. If the mineral is immersed in water with a temperature differing by a few degrees from that of the air a network of cracks result, destroying its high optic qualities.

We examined the shops where large-size plateglass was made. The glass was monstrously large. Immense sheets of window glass were smelted in a continuous band. Separate shops produced highest grades of cutglass variously stained by salts of rare earths and uranium. However, the shop of artistic drawings proved the most interesting. A vase of purest crystal was covered by a thin layer of paraffin, an experienced artistic engraver made an intricate pattern on the paraffin, then with a scalpel he took some paraffin off in one place, cut thin lines in another and before us appeared a picture of a forest and a deer hunt. This pattern was later reproduced. By means of a special apparatus the contours of the pattern were traced and it was reproduced on dozens of other vases covered with paraffin. On all of them we gradually saw the picture of a forest and a deer hunted down by dogs. Then the vases were placed in special lead-lined furnaces and the latter were filled with vapours of poisonous fluorine compounds. The hydrofluoric acid corroded the glass that was not covered by paraffin penetrating now deeper and now only a little so that the surface just turned frosted. Later the paraffin was melted in hot al-



Drawing glass cylinders. When the cylinders reach a length of about 10 metres they are straightened out and cut into separate plates. The picture on the right shows production of plate glass at a glass plant

cohol, sometimes in water or by mere heating, and we beheld a beautiful and delicate etching made by fluorine vapours. All that had to be done now was to deepen the etching in some places by means of rapidly revolving cutters and the job was completed.

SHEET 5

K.Scheele

At last, among my notes and recollections of fluorine and its minerals I found the following notes from a university chemistry course.

"Fluorine is a gaseous element with an unpleasant pungent odour; it is exceedingly active chemically. It combines with nearly all the elements, even with gold, exploding or heating brightly as it enters into combination. It is not without reason that it was so hard to obtain. It was obtained in pure form in 1886, though it had been discovered by Scheele in 1771."

In nature it is known only in the form of salts of hydrofluoric acid, chiefly as calcium fluoride, i.e., the beautifully coloured mineral called fluorite.

However, fluorine also abounds in nature in other compounds; for example, apatite contains up to three per cent of it.

In its geochemical history it is connected with volatile sublimates from molten granite magmas, but is also rather rarely encountered in the form of marine sediments which yield a certain accumulation of fluorides from organic substance.

Pieces of fluorite are used for optic glasses which, unlike ordinary glass, also lets through ultra-violet rays; it is used as a decorative stone in beautifully coloured trinkets.

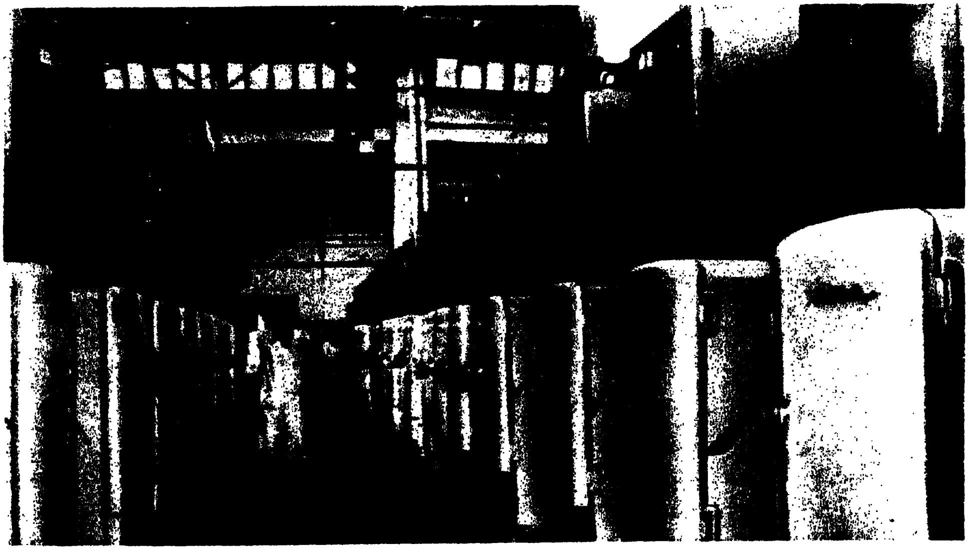
Teeth: healthy and corroded by fluorine

However, the chief use of fluorine is based on its capacity for facilitating the melting of metals. It is also used in the production of hydrofluoric acid, which is a very strong solvent and corrodes glass and even rock crystal.

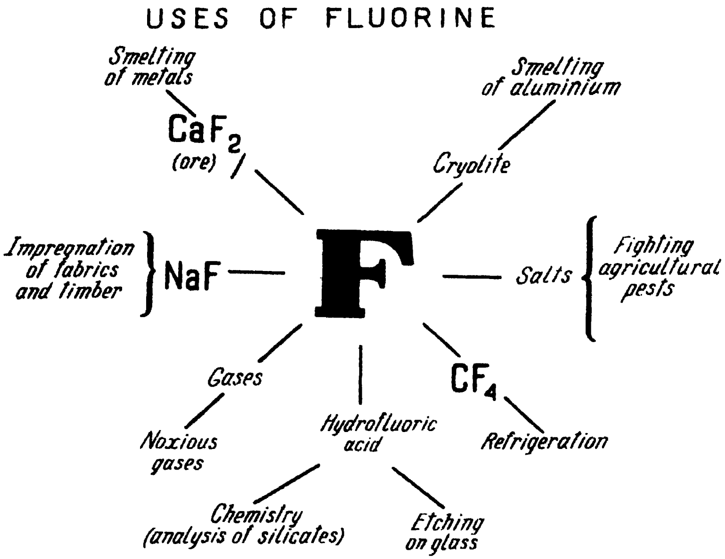
As a binary salt of sodium and aluminium hydrofluoric acid forms the mineral cryolite which is required for the electrolysis of metallic aluminium. Fluorine plays an enormous part in the life of plants and other living organisms, but an excess is harmful and causes a number of diseases.

It also plays an important part in the life of the sea where it accumulates partly by biological processes (shells, bones, teeth) and partly in the form of complex carbonates and especially, phosphates (phosphorites). Sea-water contains one milligram of fluorine per litre, while oyster shells contain twenty times as much.

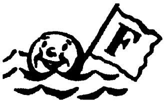
While analyzing the properties of fluorine on the basis of Mendeleyev's table scientists have recently discovered a new remarkable use for fluorine, namely, they have learned to produce a special sub-



Checking up on electric refrigerators at the Likhachov Plant



Main uses of fluorine in industry

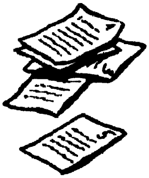


stance—carbon tetrafluoride—which is not poisonous, does not explode when mixed with air, is very stable and is capable of changing from the solid to the gaseous state with a great absorption of heat. This property has made it possible to use carbon fluoride in special refrigerators. It has been possible to develop tremendous refrigerators for preserving various foodstuffs only by the use of carbon tetrafluoride.

CONCLUSION

I told you in my own words the contents of the five sheets I had found in my paper-case. They seem to exhaust the chapter on this remarkable natural element, but its future is much greater. The most complex gaseous products of the future are connected with fluorine. There are no poisons more dangerous than the combinations of this element and at the same time there is no better way for preserving foods inexpensively in small cabinets by maintaining temperatures as low as minus 100° C.

Very little is known about fluorine as yet. It has immense potentialities which arise from the peculiar properties of its complex compounds, and it is now hard to foresee its future uses in the national economy and its fate in future engineering.



ALUMINIUM—METAL OF THE 20TH CENTURY

Al 13
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Aluminium is one of the most interesting chemical elements. It is interesting not only because in a space of several decades it has rapidly won an important place in our life, our industry and the leading branches of our national economy and together with magnesium has created the winged power of the plane, but also because of its properties and, primarily, its geochemical role. The point is that aluminium, whose acquaintance civilized humanity has made only recently, is one of the most significant and most abundant chemical elements.

You and I know very well that under the cover of clays and sands, which were formed at different times as a result of weathering and destruction of massive rocks, there is a continuous stony shell of the earth or, as it is often referred to, the earth's crust that envelops the whole globe.

This stony shell is at least 100 kilometres thick and maybe, as it is now supposed, even much thicker. In the interior this shell gradually changes to another—an ore shell which contains iron and other metals and, finally, in the centre of the earth there is, apparently, an iron core.

The stony shell forms enormous projections—continents—on the earth's surface. Folds in the shape of long mountain ranges have, in turn, come to be formed on the continents.

The stony shell of the earth which composes the base of the continents and their mountain ranges is made up of alumosilicates and silicates. The alumosilicates consist, as their name indicates, of silicon, aluminium and oxygen. This is why the stony shell is often

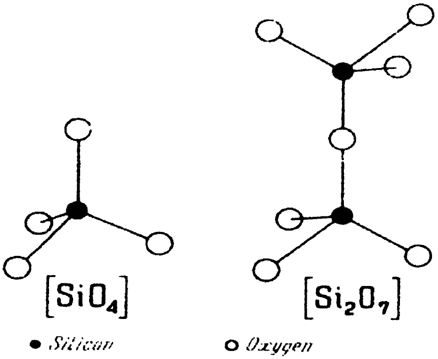
Cryolite mineral–aluminium and sodium fluoride. It is brought to Europe from Greenland. Cryolite is used for the production of metallic aluminium

called SiAl, which is a combination of the first syllables of the names—*Silicon* and *Aluminium.*

This shell, formed mainly of granite, consists of approximately 50 per cent oxygen, 25 per cent silicon and 10 per cent aluminium by weight. Thus, aluminium is the third most abundant chemical element and the most plentiful metal on earth. There is more aluminium on the earth than iron.

We are the chief elements in the earth's crust
O
Si
Al

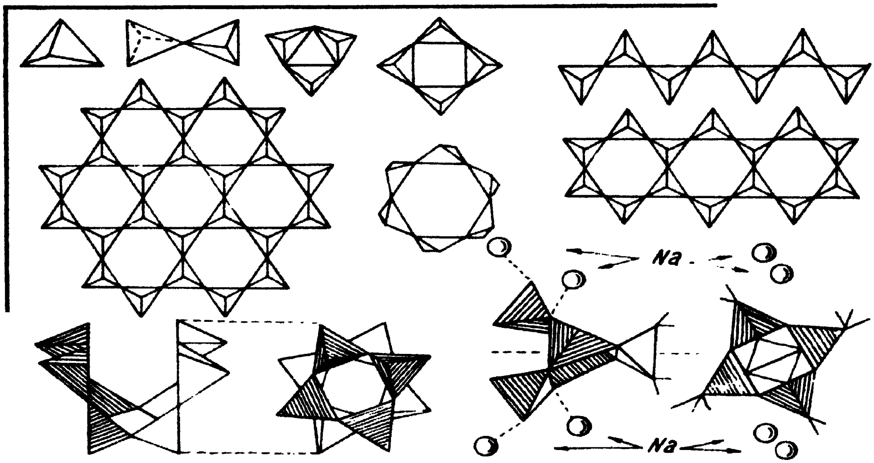
Aluminium, silicon and oxygen are, together, the chief elements of which the earth's crust is made; in the stony shell of the earth they form various minerals. These minerals are combinations of atoms whose centre is occupied either by an atom of silicon or an aluminium atom, while around them the atoms of oxygen arrange themselves regularly in four corners forming a tetrahedron.



Silicon-oxide tetrahedrons

Thus aluminium-oxygen tetrahedrons arise in addition to those of silicon-oxygen. In these cases aluminium plays a dual role: it is either arranged, like other metals, between the silicon-oxygen tetrahedrons binding them to each other, or it takes the place of silicon in some of the tetrahedrons.

It is just from these silicon and aluminium tetrahedrons combined in various ways that many of the most important minerals of the earth's crust are formed under the general name of alumosilicates. At first sight the intricate pattern in the arrangement of the aluminium,



Various combinations of silicon-oxide tetrahedrons—single tetrahedrons, double (sandglass), rings, chains, ribbons and flat networks of hexagonal rings. The bottom row shows frame structures of feldspar and natrolite (a mineral from the zeolite group) in two projections silicon and oxygen atoms reminds us of fine lace or rug ornaments. This picture could be ascertained only by means of X-rays, which photographed, as it were, the internal structure of the minerals.

Let us recall how drab and monotonous the stones appeared to us in our childhood and what an intricate and varied picture arises before us now as we penetrate into their structure.

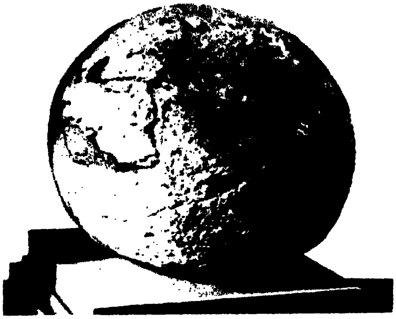
Some alumosilicates are very abundant. Suffice it to say that more than half the earth's crust is composed of minerals called feldspars. They form part of granites, gneisses and other stony rocks which envelop the earth by a sort of continuous stony armour and jut out as powerful mountain ranges.

Vast accumulations of *clays*, consisting of 15 to 20 per cent aluminium, were deposited on the earth's surface as a result of weathering of the feldspars over a period of thousands of years. The aluminium discovered in the composition of these widespread rocks was even called "alum earth," though this name has not persisted and is now used somewhat altered to designate its oxide—*alumina*.

Fortunately, we find aluminium in nature not only in this intricate composition whence it is rather hard to extract. We find a considerable amount of aluminium precisely in the form of alumina, its natural compound with oxygen. This compound is encountered in widely differing forms.

We find the anhydrous aluminium oxyde (Al_2O_3) in the form of the mineral corundum noted for its remarkable hardness and, sometimes, unusual beauty. The transparent varieties of alumina, which in addition to aluminium and oxygen contain only diminutive amounts of elements—dyes—of chromium, titanium and iron, belong to the first-class precious stones. What a variety and wealth of colour is imparted to alumina by a negligible admixture of some substance or other! These are the brilliant red ruby and blue sapphire which have fascinated man

Needles of zeolite, so-called natrolite, in igneous phonolite. The sample is in the collection of the Mineralogical Museum of the U.S.S.R. Academy of Sciences



Sample of bauxite of spherical form—aluminium ore from the "Krasnaya Shapochka" deposits in the Urals

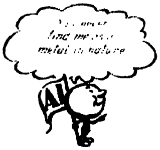
from time immemorial. So many fairy-tales are told about these stones! Man has long been using the less pure, opaque, brown, grey, bluish and reddish crystals of corundum which are inferior in hardness only to diamonds.

With their aid we process various hard materials, including the shiny steel of tools, arms and machinery.

We are all familiar with the fine crystals of the same corundum mixed with magnetite and other minerals, the so-called emery; you have probably cleaned your pen-knife with emery many a time.

Corundum could naturally serve as an easy source for obtaining metallic aluminium, but it is very valuable in itself and there is not much of it in nature.

Since time immemorial, since the very dawn of human culture, since the stone age, man has extensively utilized granites, basalts, porphyries, clays and other alumosilicate rocks, constructing cities, erecting buildings, creating works of art, manufacturing utensils and producing ceramics, faience and porcelain.



But for thousands of years man never even suspected the noble properties of aluminium, the metal which these rocks concealed.

Never and nowhere in nature is aluminium found in the metallic form, but always in various compounds absolutely different in their properties and appearance from the metal aluminium.

It required the genius of man and his persistent labour to bring this wonderful metal to life.

The first time it was possible to isolate a small amount of the shiny silvery metal was about 125 years ago. At that time nobody thought it would ever play any part in the life of man, especially since it was so very hard to produce. But then, in the beginning of last century, several scientists managed by means of electrolysis to isolate aluminium

Ready-made ingots of metallic aluminium

on a cathode under a crust of slags from aluminium compounds smelted at high temperatures. This was a pure silvery metal—"silver from clay," as they said at that time.

This method of aluminium production was employed in plants and the metal soon began to be widely used. It resembles silver in colour and its properties have really proved wonderful.

Pure aluminium oxide is not extracted from clay. As a convenient ore nature gives us a *hydrous* aluminium oxide (hydrate of alumina) in the form of the minerals of diaspore and hydrargillite. Frequently mixed with iron oxides and with silica these minerals form deposits of clay-like or stone-like rocks—bauxites—mainly amid littoral sedimentations.

Bauxite contains a very large amount of aluminium oxide (50 to 70 per cent) and is the principal industrial aluminium ore. Soviet chemists have developed and mastered a new process of changing the Khibiny mineral, called nephelite ($Na_2Al_2Si_2O_8$), into aluminium oxide. Attempts have lately been made to utilize also disthene shales, which contain 50 to 60 per cent aluminium oxide, and other minerals: leucite and alunite. But neither of these minerals, except nepheline, can replace bauxite.

The production of metallic aluminium is based on two independent processes. First of all a pure anhydrous aluminium oxide—alumina—is extracted from the bauxite by a rather complex process. The aluminium oxide is then electrolyzed in special baths lined with graphite.

The alumina powder is loaded into these baths in mixture with *cryolite* powder. A high-intensity electric current develops a high temperature (about 1,000° C.); the cryolite melts and dissolves the alumina which is subsequently decomposed by the current into aluminium and oxygen. The floor of the bath serves as the cathode (negative pole) and the molten aluminium accumulates on it. Through a special tap it is let out and poured into moulds where it hardens in the form of shiny silvery bars.

One hundred years ago it was very hard to produce this light white metal and a pound of aluminium cost forty gold rubles. Today the might of rivers, transformed into electric power, makes it possible to produce it in enormous quantities.

Some of the properties of aluminium are well known to everybody. It is a very light metal, nearly one-third the weight of iron. It is very malleable and at the same time sufficiently strong; it can be drawn into wire and rolled into thinnest sheets. No less remarkable are its chemical properties. On the one hand, it does not seem to fear oxidation; we know this from the behaviour of aluminium wares, pots, pans and cans. But it also has a great affinity for oxygen. Mendeleyev was one of the first to notice this apparent contradiction. The point is that after smelting the aluminium, which shines like silver, becomes covered with a dull oxide film which protects it from further oxidation. Not every metal has this capacity for self-defence. Iron oxide, for example, well-known rust, in no way prevents the further destruction of the metal; it is too friable and penetrable to air and water. The thin oxide film which covers aluminium is, on the contrary, very dense and elastic and serves as a reliable protection.

When heated aluminium greedily combines with oxygen, changing to aluminium oxide and liberating an enormous quantity of heat. This property of aluminium to liberate heat during combustion has been used by industry for smelting other metals from their oxides by mixing them with powdered metallic aluminium. In this process of aluminothermy the metallic aluminium abstracts the oxygen from the oxides of the other metals and reduces them.

If you mix, for example, iron oxide powder with pulverized aluminium and kindle the mixture with a magnesium ribbon a violent reaction will develop before your very eyes, an enormous amount of heat will be liberated, the temperature rising to 3,000° C. The iron displaced by the aluminium melts at this temperature, and the aluminium oxide which forms rises as a slag to the surface. Man has made use of this activity of aluminium for producing certain refractory and technically valuable metals.

Metallic titanium, vanadium, chromium, manganese and other metals are smelted this way. Since a high temperature is developed in aluminothermy, the mixture of iron oxide and aluminium, known as thermite, is used for welding steel.

We could hardly name many elements that have made so fast and brilliant a career as aluminium.

Aluminium has very rapidly made its way into the automobile, machine-building and other branches of industry, in many cases replacing steel and iron. In naval ship-building its use has wrought a revolution, making it possible, for example, to build "pocket battleships" (ships the size of light cruisers with the power of dreadnoughts).

Pouring aluminium

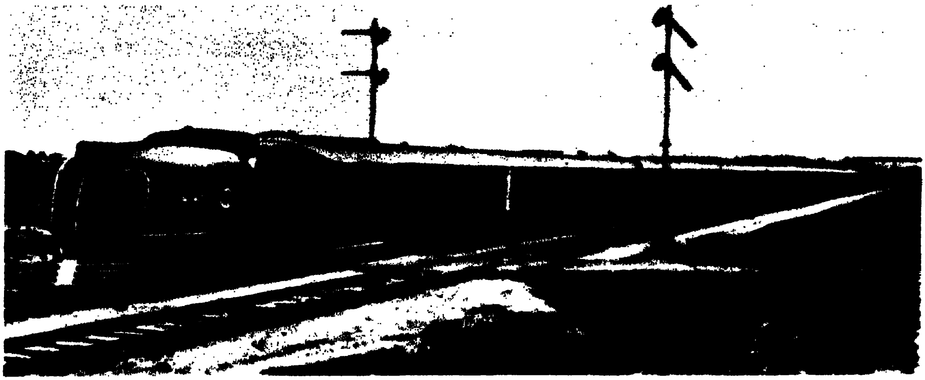
Man has learned to produce this "silver" from natural minerals on an enormous scale, and the "silver from clay" has enabled him fully to conquer the air.

Aluminium and its light alloys offer the best material for the construction of rigid airships, fuselages, wings and all-metal planes.

This new industry, which has so extensively utilized aluminium, has grown with wonderful speed before our very eyes.

When we see a plane flying over our heads let us recall that aluminium makes up 69 per cent of its weight (without the motor) and that even in an aircraft engine the weight of aluminium and magnesium, the two lightest metals, constitutes close to 25 per cent.

In addition to the vast consumption of aluminium by the heavy



Modern express train. Built mainly of light aluminium alloys

industry, the construction of all-aluminium railway carriages, and the utilization of this metal in machine-building (especially aircraft-building) hundreds of thousands of tons of it are used in the manufacture of aluminium wires and parts employed in the electrical industry.

And still this does not exhaust the uses of the metal.

Let us add the reflective mirrors in searchlights, the main parts of shells and machine-gun cartridge belts, the flares and the aluminium powder mixed with iron oxide in incendiary bombs. Let us recall the tremendous importance of artificial crystalline alumina (electrocorundum, alundum) now produced from the same bauxites and used for *abrasives* chiefly in machining metals.

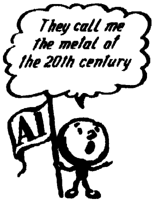
By crystallizing pure aluminium oxide with an addition of dyes we produce rubies and sapphires in no way inferior to the natural stones either in hardness or beauty. We use them mainly as durable support stones in the principal parts of precision instruments: watches, scales, electric meters, galvanometers, etc.

We coat iron with fine aluminium powder and produce a sort of rustproof aluminium white metal. The same powder serves for the manufacture of lithographic ink. Of late it has also earned the appreciation of artists who paint on wood.

Why do we call aluminium the metal of the 20th century?

Because owing to its remarkable properties it is increasingly made use of and its enormous reserves are inexhaustible; we have every reason to believe that aluminium is now becoming part of everyday life like iron did in its time.

In a few centuries they will probably call our time the aluminium age.


They call me the metal of the 20th century
Al

BERYLLIUM—METAL OF THE FUTURE

Be 4
9.02

Historians tell us that Nero, the Roman emperor, liked to watch fighting gladiators in the circus through a large crystal of a green emerald.

When Rome, set on fire by his order, was burning he took delight in the raging fire by watching it through a green emerald glass in which the red colours of the fire blending with the green of the glass appeared black and sinister.

When the artists of ancient Greece and Rome, who did not know any diamonds, wanted to engrave somebody's face in stone in order to immortalize him and show their admiration for him they used a pure emerald from the Nubian Desert in Africa.

Like the emeralds, golden-yellow chrysoberyls found in the sands of Ceylon, greenish-yellow snake-coloured beryls and bluish-green aquamarines the colour of sea-water were also always highly valued in India. The euclase, one of the rarest minerals of delicate "blue water," as the jewellers put it, and the fiery-red phenacite, which fades in the sun in the course of a few minutes, came to be known later.

All these stones have long attracted man's attention by the beauty of their play and the remarkable sparkle and purity of colour, and though many chemists tried to divine their chemical nature they found nothing new in them and erroneously believed them to be compounds of ordinary alumina.

Beryls and emeralds were mined two thousand years ago in the intricate bends of Cleopatra's famous underground galleries in the arid Nubian Desert.

Beryls. The board shows a hexagonal section of a crystal

The green stones extracted from the interior of the earth were delivered by camel caravans to the Red Sea coast and thence to the palaces of Indian rajahs, the shahs of Persia and the rulers of the Ottoman Empire.

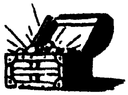
In the 16th century, after the discovery of America, remarkably beautiful and big dark-green emeralds were brought to Europe from South America.

After a hard struggle against the Indians the Spaniards seized the fabulous wealth of emeralds mined in Peru and Colombia and brought to the altar of the goddess whose sacred image was an emerald crystal the size of an ostrich egg.

They looted the temples of the local population, but the precious stone deposits in the inaccessible mountains of Colombia had long remained a secret to the invaders and the Spaniards got to the mines and took possession of them only after a long struggle.

By the end of the 18th century all these mines were exhausted.

At the same time aquamarines of enchanting colours began to be found in the sands of sunny Brazil. It is not without reason that this stone was named aquamarine, i.e., "the colour of sea-water," since



its colours are as changeable as those of the southern sea in all the magnificence and diversity of its shades familiar to every one who has ever been on the Black Sea coast or has seen Aivazovsky's remarkable paintings.

While gathering brushwood in a forest in 1831 a Urals peasant, named Maxim Kozhevnikov, found the first Russian emerald under an uprooted tree.

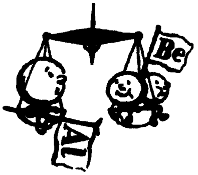
The emerald mines were worked for more than 100 years. Trainloads of light-coloured beryl were extracted from the earth but only the bright-green stones were faceted, while the rest were discarded.

. . . Such is the past history of the green precious stones which were described under the name of "beryllos" several centuries B.C.

Such is the picture of the beginning of the history of the metal of the future, called beryllium, as it comes to our mind.

But until 1798 it never occurred to anybody that these beautiful bright stones contained a yet unknown valuable metal.

At a solemn sitting of the French Academy on the 26th Pluviôse of the sixth year of the Revolution (February 15, 1798) the French chemist Vauquelin made the astounding statement that what had formerly been considered alumina or alum earth in a number of minerals was really an absolutely new substance for which he proposed the name of glucinum (from the Greek word meaning sweetness) because its salts tasted sweet to the chemist.



This statement was soon confirmed by numerous analyses of other chemists, but it turned out that the minerals contained but little of this new metal, usually only from four to five per cent. When chemists began studying the distribution of beryllium in detail they found that it was generally a very rare metal. The earth's crust contains no more than 0.0004 per cent of it, and still there is twice as much beryllium in the earth as lead or cobalt and 20,000 times as little as its brother-metal aluminium with which it had always been confused.

Then our chemists and metallurgists went to work on this metal, and an entirely new picture has presented itself to us in the last fifteen years; it is not without reason that we can now call beryllium the greatest metal of the future.

It really appears that this silvery metal is twice as light as the well-known light aluminium. It is only 1.85 times the weight of water,

Giant bright green opaque beryl from a feldspar quarry. Weight 18 tons

whereas iron is 8 times as heavy and platinum is more than 20 times as heavy.

It yields fine and also very light alloys with copper and magnesium.

True, the extensive utilization of beryllium is still kept secret (it is a military secret of a number of countries) but we already know very well that the alloys of this metal find ever wider application in the aviation of all countries, that to produce good automobile spark-plugs a beryllium powder is added to the porcelain mass, that thin metallic plates made of beryllium easily transmit X-rays and that the alloys of beryllium are amazing for their lightness and strength. Particularly remarkable are springs made of beryllium bronze.

Beryllium is really one of the most remarkable elements of tremendous theoretical and practical importance.

We have already learned to prospect for it; we know it is found in regions of granite massifs, where it concentrates in the last breaths of molten granites and accumulates together with other volatile gases and rare metals in the final extracts of the remnants of granites hardening in the interior.

Crystals of beryl in feldspar

In these lodes, which we call granite pegmatites, we encounter beryllium in the form of fine sparkling precious stones.

We also find it with other ores; we know where to look for it because we know its behaviour, character and properties. It is prospected for on an ever growing scale.

The paths travelled by beryllium in the earth's crust suggest to us its uses in industry. Technologists are studying the methods of its extraction from ores, while metallurgists are learning to use it in super-light alloys for the construction of planes.

Mastery of the air and daring flights of planes and balloons into the stratosphere are impossible without light metals, and we can already foresee that beryllium will come to the aid of the modern

Large crystal of beryl

aircraft metals—aluminium and magnesium. Our planes will then fly at a rate of thousands of kilometres per hour.

The future belongs to beryllium!

Geochemists, you must search for new beryllium deposits.

Chemists, learn to separate this light metal from its fellow-traveller—aluminium.

Technologists, make the lightest possible alloys that do not sink, are hard as steel, elastic as rubber, strong as platinum and eternal as precious stones. . . .

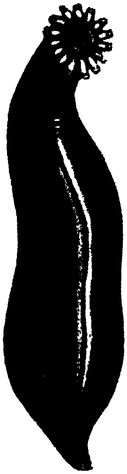
Today these words may sound fantastic. But think of the fantasies that have become reality and daily practice before our very eyes; we seem to forget that only some 20 years ago our radio and talking pictures sounded like the greatest fantasy.

VANADIUM—BASIS OF THE AUTOMOBILE

V 23
50,95

"Had there been no vanadium there would be no automobile," said Henry Ford who had begun his career precisely with successfully utilizing vanadium steel for the axles of his car.

"Had there been no vanadium certain groups of animals could not exist," said Y. Samoilov, well-known Russian mineralogist, when it was discovered that the blood of some Holothurioidea contained close to 10 per cent of this metal.



One of Holothurioidea containing vanadium in its blood

Some geochemists believe that had there been no vanadium there would be no oil in the earth; they ascribe to vanadium a special influence on the formation of oil.

This remarkable metal was long unknown to man; controversies and a struggle for obtaining it continued for many decades.

"Long, long ago, in the extreme North there lived Vanadis, the beautiful and beloved goddess. One day somebody knocked on her door. The goddess was comfortably seated in an armchair. 'Let him knock again,' she thought. But the knocking ceased and somebody walked away from the door. The goddess wondered who the modest and diffident visitor was. She opened a window and looked out. She saw a man named Wöhler who was hastily departing from her palace.

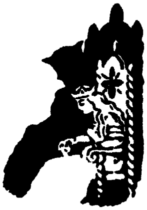
"Several days later she heard someone knocking on the door again but this time the knocking continued until she went and opened the door. Before her stood a handsome young man by the name of Nils Sefström. They soon fell in love with one another and gave birth to a son whom they named Vanadium. This is the name of the new metal discovered in 1831 by the Swedish physicist and chemist Nils Sefström."

Andrés Manuel del Río, professor of Mineralogy and Chemistry in Mexico (1764-1849)

Thus begins the story of vanadium and its discovery in the letter of the Swedish chemist Berzelius. But in his story he forgets to mention that somebody else had knocked on the goddess' door before and that this remarkable person was the famous don Andrés Manuel del Río, one of the purest souls of old Spain, an ardent champion of Mexico's liberty and fighter for its future, fine chemist and mineralogist, mining engineer and mine-surveyor who was able to imbibe the ideas of the foremost scientists of the time. As early as 1801, while studying the brown lead ores of Mexico Andrés del Río discovered in them what appeared to him a new metal. Since its compounds were of all possible colours he named it panchromium at first, but later substituted erythronium, i.e., red, for it.

However, Andrés del Río was unable to prove his discovery. The chemists to whom he sent samples took the element contained in the brown lead ore for chromium; the same mistake had been made by the German chemist Wöhler who so diffidently and unsuccessfully knocked on the goddess Vanadis' door.

After long doubts and many unsuccessful attempts to prove the independence of this metal the young Swedish chemist Sefström found a solution. Blast-furnaces for smelting iron were being built in different parts of Sweden at that time. It turned out that the iron ores of some mines yielded brittle iron, while high grades of flexible and ductile

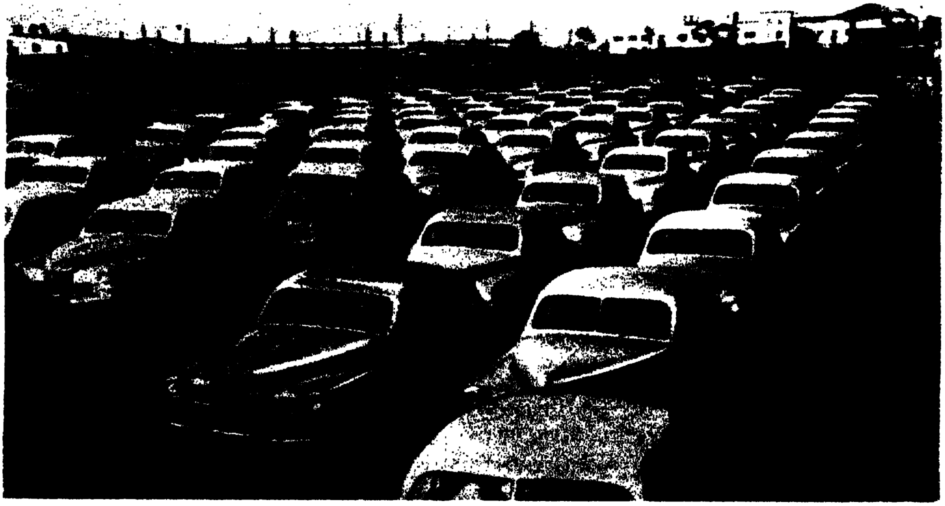


metal were obtained from other mines. In checking up on the chemical composition of these ores the young chemist soon isolated a special black powder from the magnetite ores of the Taber Mountain in Sweden.

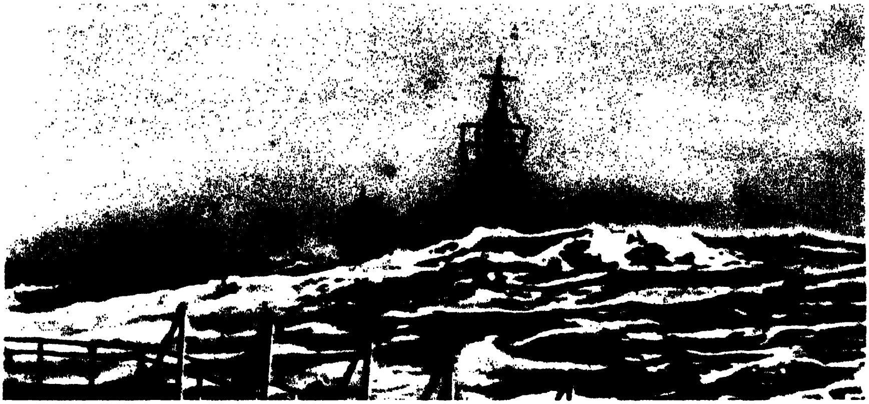
Continuing his research under the supervision of Berzelius he proved that he was dealing with a new chemical element and that the same element was contained in the Mexican brown lead ore spoken of by Andrés del Río.

What was Wöhler to do after this indubitable success of the young Swede? In a letter to his friend he wrote: "I was a real ass to have overlooked the new element in the brown lead ore, and Berzelius was right when he ridiculed me for so timidly and unsuccessfully knocking on the door of the goddess Vanadis."

The remarkable metal vanadium has now become one of industry's most important metals. But it was very long before man finally laid his hands on it. At the outset a kilogram of vanadium cost 50,000 gold rubles, while now it costs only ten rubles. Only three tons of it were produced in 1907 because nobody wanted it, whereas today a



Passenger cars and lorries just come off the conveyer



Battleships which need vanadium steel

keen struggle is being waged for vanadium deposits in all countries. Its properties are remarkable and the need for it is great in every country. In 1910 150 tons of the metal were produced and deposits were discovered in South America; in 1926 its production reached 2,000 tons; now it exceeds 5,000 tons.

Vanadium is one of the most important metals for the automobile, for armour and armour-piercing shells which go through plates of the best steel 40 centimetres thick; vanadium is the metal of the steel plane and of fine chemical products; it is used in the production of sulphuric acid and various fine dyes.

What are its main merits? It influences steel by making it more resilient and less brittle; it prevents the steel from recrystallizing under the action of shocks and jolts, and this is precisely what automobile axles and motor shafts need because they are subject to a lot of shaking.

No less remarkable are the salts of this metal—green, red, black as ink, yellow and golden as bronze. They yield a whole scale of beautiful colours for porcelain, photo paper and special inks. They are also used in treating the sick....

There is no need enumerating all the remarkable uses of this metal;

we must only mention one more. Vanadium helps in the production of sulphuric acid, this central nerve of the chemical industry. In this case it behaves very "cunningly"; it only helps the chemical reaction, it catalyzes it, as the chemists say, itself remaining unchanged and unspent. True, some substances poison and spoil it, but there are medicines for this, too. The presence of metallic vanadium and of some of its salts seem to have a mysterious effect on the production of the most complex organic compounds which cannot be produced without its participation.

But if vanadium is so wonderful a metal why do we know so little about it? Why have some of you readers never even heard of it before? Besides, only about 5,000 tons of it is produced in the world annually; and this is 20,000 times as little as the annual output of iron and only five times as much as that of gold.

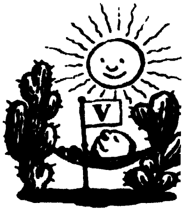
Something is, evidently, wrong with its deposits and production, and to find out what it is we must ask our geologists and geochemists. Here is what they tell us about the behaviour of this metal in the earth's crust.

It seems there is quite a bit of vanadium in our earth. In the accessible part of the earth's crust our geochemists estimate an average of 0.02 per cent, and this is not so little at all if we recall that the earth's crust contains 15 times as little lead and 2,000 times as little silver. There is essentially just as much vanadium in the earth as there is zinc and nickel, and the last two metals are produced in hundreds of thousands of tons.

But not only the earth and the accessible earth's crust contain vanadium. There are probably rather large quantities of vanadium where native iron is concentrated. This is betokened by the meteorites which fall on our earth. Their metallic iron contains from two to three times as much vanadium as the earth's crust. In the spectrum of the sun our astronomers see the sparkling lines of its atoms, but this is just what grieves the geochemists. There is a lot of vanadium everywhere; this odd metal abounds in the universe, but there are few places where it is concentrated and could easily be mined for industry. It is really found in most of the iron ores, and where its content reaches at least tenths of one per cent industry begins to produce it. The possibility of extracting this costly metal from thousands of tons of iron is becoming interesting and even profitable.

There is as much of me in the earth as there is zinc and nickel
V

Titano-magnetite mine in the Urals; vanadium is extracted from this ore



When chemists discover an ore containing one per cent vanadium the newspapers report the discovery of a rich vanadium deposit. Some internal chemical forces, apparently, always strive to disperse the atoms of this metal. Our science must find out what concentrates and accumulates these dispersed atoms and what is likely to break their passion for dispersion and migration. Such forces do exist in nature, and studying the deposits of this metal we are now reading remarkable pages concerning the processes which concentrate the atoms of vanadium and force them to accumulate.

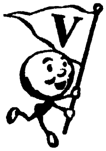
Vanadium is primarily a metal of deserts; it is afraid of water which easily dissolves it and transports its atoms over the earth's surface; it is also afraid of acid soils. It finds "peace" only in the southern latitudes where there is a lot of oxygen in the air and where veins of sulphide ores are eroded. In the hot sands of Rhodesia and in its native land (sunny Mexico) amid Agaves and cacti, it creates yellow-

brown iron hats, brown hills resembling soldiers' helmets which cover the outcrops of the sulphide ores.

We see the same compounds in the old deserts of Colorado and encounter them in the ancient Permian desert in the region of the Urals bordering in the East on the expanding range of the great Uralides. The salts of vanadium are formed everywhere under the hot sun and in sands, and accumulate from dispersed atoms in deposits of industrial importance.

And still its reserves are very small; its atoms strive to escape the hands of man; but there are some powerful forces that retain vanadium and do not let it disperse; these are cells of living substance, organisms whose blood corpuscles are built of vanadium and copper rather than of iron.

Vanadium accumulates in the bodies of certain marine animals, especially sea-urchins, ascidia and Holothurioidea which cover thousands of square metres of bays and sea coasts. It is hard to say where they catch the atoms of vanadium since it has been impossible to find this metal in the water itself. These animals, apparently, possess some special chemical ability for extracting vanadium from particles of food, silt, remains of seaweeds, etc. Not a single chemical reagent works with the efficiency of a living organism which is able out of millionths of a gram to accumulate in its body and leave after its death such enormous quantities that man can extract metals from it for his industry.

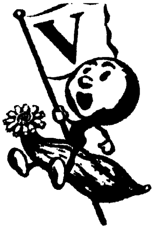


But as great as the forces of life are, there are still few real deposits of this metal, it occurs in negligible quantities and is hard to extract from black asphalts, bitumens and oils. The ways its atoms accumulate on the earth's surface are a mystery, and scientists will have to do a lot more work to solve the riddle of its extraction and to be able coherently to tell its history in order that the separate links in the life of vanadium merge into one continuous chain.

We shall then know not only the past fates of this metal, but also where and how to look for it, and profound theoretical inferences will be transformed into major industrial victories.

The automobiles will get their metal for axles and the battleships and tanks will receive a higher percentage of vanadium in their armour steel. Very fine chemical reactions with the aid of vanadium catalysts will produce hundreds and thousands of new and most complex organic compounds we need for nutrition, for the economy and for culture.

This is what geochemists tell us about the deposits of vanadium. We cannot be satisfied with this; we must ask them to work harder and more persistently in order that they master this metal for the needs of the country.



GOLD—KING OF METALS

79
Au
197,2

Gold came to the attention of man a long time ago, probably in the form of glittering yellow grains in river sands.

We shall learn a lot that is remarkable and instructive if we trace the history of the use of gold in the intricate course of man's development. From the very cradle of human culture down to the imperialist wars gold has been connected with military campaigns, conquests of continents, the struggle of several generations of peoples, crime and blood.

The Argonauts in Kolchis (ancient name of Georgia) examining the golden fleece. Old engraving

Gold plays an enormous part in the ancient Scandinavian sagas, and the struggle of the Nibelungs is a struggle for freeing the world from the curse of gold and its power. The ring forged from the gold of the Rhein symbolizes the principle of evil. Sigfried must free the world from the power of gold and overthrow the gods of Valhalla at the cost of his life.

Ancient Greek mythology has a myth about the voyage of the Argonauts to Kolchis in quest of the golden fleece.

They were supposed to find the fleece, i.e., sheepskins covered with gold dust, on the Black Sea coast, in present-day Georgia, and take them away from the dragon who was guarding them.

We can read about the struggle for gold on the Mediterranean in the ancient Greek legends and in Egyptian papyri. For the construction of the famous temple in Jerusalem King Solomon required a great deal of gold; he undertook several campaigns to the ancient country Ophir which historians are vainly trying to find at the source of the Nile and in Ethiopia. Some scientists believe the word "Ophir" to mean merely "wealth" and "gold."

There is a legend about ants that extract gold. There are many versions of this legend in the interpretation of different investigators.

The basis of this legend is the story about one of the Indian tribes that lived in a sandy desert where the ants were as large as foxes. Together with sand these ants dug out of the interior of the earth a lot of gold which was carried away by the inhabitants on camels. Herodotus confirms this story; something of this sort can also be found in Strabon who wrote in 25 B.C. Pliny cites a somewhat different version, but at any rate the European and Arab writers alike repeatedly turned to this story in the Middle Ages. There is no plausible explanation of this legend as yet; the most plausible is probably the one which tells us that in Sanscrit the words "ant" and "grain" (of alluvial gold) are expressed by the same sounds. The origin of the legend is probably based on this similarity between the words "particle of gold" and "ant."

Wonderful gold articles were found in the ancient treasures of the Scythian epochs in the South of Russia. These remarkable

Golden comb with picture of battle between Scythians and Greeks. Culture of the 5th and the end of the 4th centuries B.C. Solokha Burial Mound (Ukrainian S.S.R.). Collection of the State Hermitage articles made by unknown Scythian jewellers are chiefly representations of animals in rapid motion. They are kept at the Hermitage together with similarly fine gold articles found in the famous Siberian treasures.

Kidney-shaped gold nuggets. Kachkar South Urals

The ancients always attached great importance to gold. Alchemists used the symbol of the sun for it. While the Slav, German and Finnish peoples had the letters G, Z, O and L in the root of the word (*zoloto* [Russian] and gold), the Indo-Iranian peoples put the letters A, U and R in its root, hence, the Latin word "aurum" and the modern chemical symbol for gold—Au.

Philologists have conducted special research in their attempts at finding the roots of the term "gold." These investigators have tried to locate the centres of gold in the ancient world. It is interesting to note in this connection that in Egypt the hieroglyph for gold was a kerchief, a bag or a trough, which, apparently, denotes the method of mining it.

Gold was distinguished by its quality and colour. Sands whose location was described in detail in a number of written monuments were the source of gold in Egypt. Gold was found in different parts of North-western Egypt, as well as along the Red Sea coast, in the sands remaining from the ancient granites in the region of the Nile and, especially, in the region of Qoseir. Old texts indicate numerous points where gold was mined. There were also ancient gold-fields in the Arabian and the Nubian deserts. There are indications that gold-mines existed two to three thousand years B.C.

Samples of wire-shaped crystalline gold in the form of hooks and spirals

Washing gold in antiquity. Old engraving

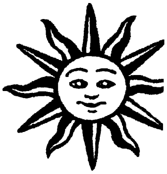
In later written monuments gold-mines are shown and very well described by a number of authors. Several texts point out that gold is connected with shiny white rock, apparently, with quartz veins, which some ancient authors incorrectly called by the Greek word *marmoros*. We know the prices, methods of mining, exploitation, etc.

The discovery of America in the 15th century wrote a new page in the history of gold. The Spaniards brought tremendous quantities of the precious metal from America; they had obtained it by means of war looting and flooded Europe with it.

Rich gold-fields were discovered in the sands of Brazil in the beginning of the 18th century (1719). A "gold rush" began everywhere, and other countries also started prospecting for gold. In Russia the first crystals of gold were found in quartz rock near the city of Yekaterinburg (now Sverdlovsk) in the middle of the same century. A remarkable discovery was made in America one hundred years later, in 1848; deposits of gold were found in the Far West, beyond the Rocky Mountains, almost on the Pacific coast in California, which was then still a mysterious region. The strike was made by John Sutter who later died a pauper.

Gold prospectors rushed there; caravans of ox-drawn waggons moved westward in quest of new luck. Before another 50 years had elapsed gold was discovered in Klondike, Alaska, which had been so recklessly and cheaply sold to the U.S.A. by the tsarist government of Russia. Jack London's stories tell us how the struggle for gold was waged in Klondike. There are photographs showing "black snakes" paving their way across snowy peaks of polar mountain ranges; these were endless streams of people carrying their meagre belongings on their backs or in small sledges and hoping to bring back piles of gold.

The first gold-fields in Transvaal, South Africa, were discovered in 1887, but this wealth did not bring the Boers, who had found it,

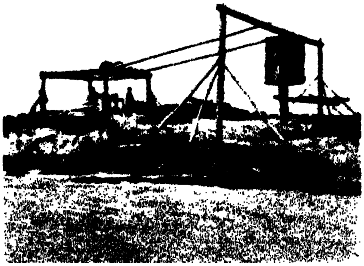


any good fortune. After a long and bloody struggle Britain managed to conquer the country and nearly exterminated the freedom-loving Boer people. More than 50 per cent of the world's gold is now mined in Transvaal. Gold is also found in Australia.

The conquest of gold has had its own very peculiar history in the U.S.S.R. In 1745 peasant Yerofei Markov found a gold vein along the Beryozovka River near Yekaterinburg in the Urals. In 1814 Brusnitsyn, a head-miner, also discovered the first gold-fields in the Urals and organized their industrial exploitation. The Urals is, thus, the cradle of the Russian gold industry. The discovery of gold-fields on the Lena River in Siberia in the second half of the 19th century caused a sensation at the time. The fields were fabulously rich and adventurers of all brands and from all countries rushed there. Some of them drove their stakes and sold the claims, others washed gold under the severe conditions of the taiga and returned rich men while still others mined

Initial exploitation of gold-bearing quartzites in Transvaal gold but spent it all on drink right there and then; there were still others, and they were in the majority, who died from scurvy and exposure.

Even greater resources were discovered in the early twenties of this century on the Aldan River.



Bell-work gold-mining using whim gin; the usual machinery in pre-revolutionary Russia

I chanced to meet one of the prospectors who had worked in the Aldan fields during the first years after their discovery. He told me about the past of the Aldan, about the rush of the adventurers who had deserted the white armies and abandoned everything in order to penetrate to the upper reaches of the Aldan and grow rich on gold. He told me about a priest who had forsaken his parish, reached with enormous hardships the sources of this river, made a raft and penetrated into an almost inaccessible region where he washed almost 900 pounds of this precious metal. He told me, furthermore, how Soviet rule came to the Aldan and the gold-mines, which had been known as the land of gold and tears, became an organized industry. Many other rich gold deposits have been discovered since.

The struggle for gold has, thus, gradually proceeded in the history of mankind. Over 50,000 tons of this metal has been produced; about half of this gold, more than 10,000 million gold rubles' worth, has accumulated in banks. The achievements of engineering have made it possible gradually to mine more and more gold, proceeding from rich to poor ores.

At first these were simple, primitive methods of production; the gold was washed in bowls, pans and later in what was called "Amerikankas"* in Russian and was used throughout the world after the discovery of gold in California.

Afterwards placer gold deposits were worked hydraulically, using powerful streams of water, while the gold dust was dissolved in cyanide

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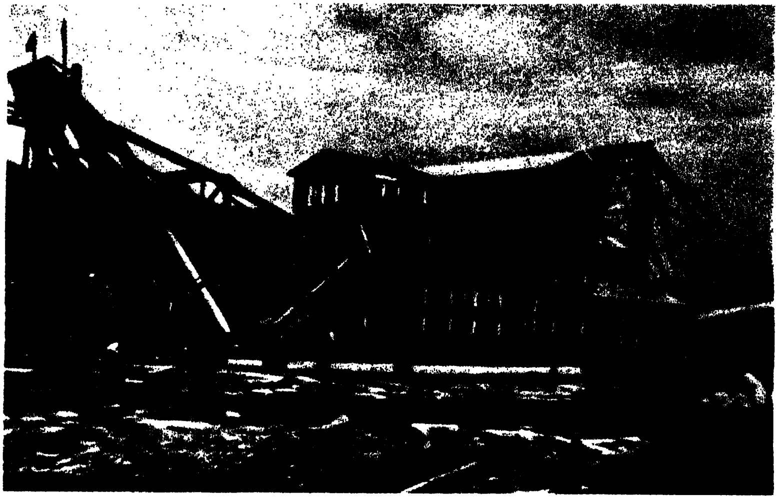
* Long narrow troughs with riffles to catch the gold.

Hydromonitor washing gold-bearing sands by a strong stream of water

solutions; finally, man learned to extract gold from hard native rocks using the most perfect methods at large mills.

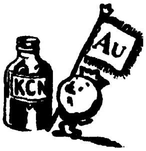
Man uses every possible means to safeguard his gold and keeps it locked up in the strong vaults of state banks, while ships on which gold is transported are escorted by battleships. Gold has been taken out of circulation in the form of coins because it wears too fast.

During the thousands of years of his cultural and economic life man has extracted no more than one-millionth of the gold contained in the earth's crust. But why has man made gold his idol and the basis of his wealth? Gold, no doubt, possesses a number of remarkable properties. It is representative of the "noble metals," i.e., the metals



In the gold-fields. Electric dredge reaching to a depth of 25 metres which do not change on the surface, retain their bright lustre and do not dissolve in the usual chemical reagents. As a matter of fact gold can be dissolved only by the free halogens, say, chlorine, or aqua regia which is a mixture of three parts hydrochloric acid and one part nitric acid, as well as by certain rare poisonous cyanic salts.

Gold has a very high specific gravity. Along with the platinum metals it is one of the heaviest elements in the earth's crust; its specific gravity reaches 19.3. It melts comparatively easily when heated to a little above 1,000° C., but it is transformed into volatile vapours only with great difficulty. To be brought to the boiling point it must be heated to 2,600° C. It is very soft and easy to forge; it is not harder than the softest minerals and in its pure state you can scratch it with a finger-nail.



Chemists determine the presence of gold by very fine methods. One atom of gold in a thousand million atoms of other metals is enough for chemists to detect it in the laboratory (i.e., they can estimate down to 10^{-10} grams). Even with our modern techniques this amount of substance cannot be weighed on any scales.

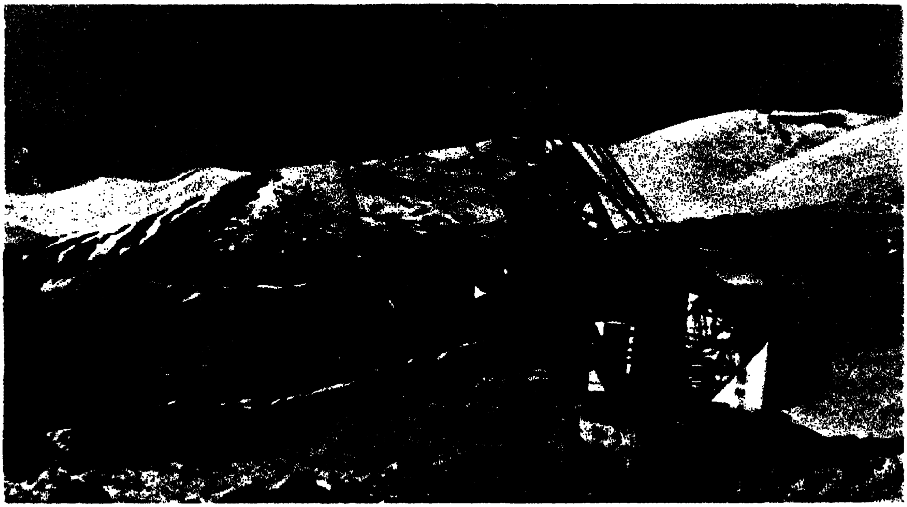
There is not so little gold in the earth's crust, but it is dispersed; chemists have now estimated that the earth contains an average of about 0.00000005 per cent gold. Just think of it, there is only twice as much silver in the earth's crust though silver is considered a much cheaper metal! The most remarkable thing is that gold is spread all through nature. It has been discovered in the hot vapours of the solar atmosphere, it is found (in lesser quantities than on earth, to be sure) in the falling meteorites, and there is some of it in sea-water. Recent experiments have shown that sea-water contains 0.0000000005 part gold, i.e., there is five tons of gold per cubic kilometre of sea-water.

Gold finds its way into granites, accumulates in the very latest molten granite magmas, penetrates into hot quartz veins and there, together with sulphides of other metals, especially, iron, arsenic, zinc, lead and silver, crystallizes at relatively low temperatures, about 150 to 200° C. Thus, large concentrations of gold are formed. When the granites and quartz veins are eroded the gold passes into placer deposits where it accumulates in the lower layers of the sands because of its stability and specific gravity. It is hardly affected by the chemical aqueous solutions which circulate through the layers of the earth's crust.

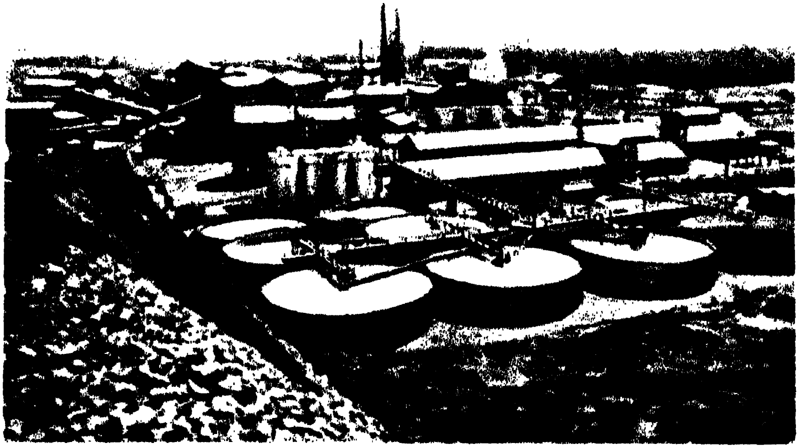
Geologists and geochemists have spent a lot of effort to learn about the fate of gold on the earth's surface. Exact research has shown that it migrates here, too.

It is not only ground up mechanically to submicroscopic size and in this state carried away in enormous quantities by rivers, but is also partly dissolved, especially in southern climates, where the rivers contain a good deal of chlorine, is recrystallized and finds itself in soils and in plants. Experiments have shown that the roots of trees absorb gold. Several years ago scientists demonstrated that gold accumulated in the grains of maize in rather large amounts. But even more gold accumulates in the ashes of some coals where its content reaches one gram per ton of ashes.

The foregoing shows that gold travels most intricate paths in the earth's crust before man extracts it. And still, whatever man has done for more than 2,000 years in the struggle for gold and as great as individual gold enterprises are, we do not know the complete history of this metal. Our information on the fate of dispersed gold is so meagre that we are unable to join the separate links of its migrations into



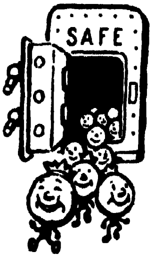
Excavators expose gold-bearing sands



Enormous tanks in which gold is dissolved by cyanidation

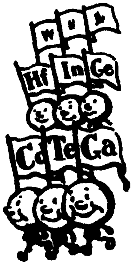
a single continuous chain. What has happened to the gold that was carried out into the seas and oceans after the erosion of the great mountain ranges and granite cliffs? What has become of the gold of the Permian Sea which has left some of the richest deposits of salts, limestones and bitumens near the Urals?

Geochemists and geologists, you still have a lot of work ahead of you. The millions of square kilometres of our gold-bearing Siberian regions offer ample opportunity for daring scientific thought!



The future of gold is not in the vaults of banks nor in the stock-exchange deals of speculators and capitalists; it will be used for other purposes. This metal is now widely utilized in Soviet science and in the exact branches of industry, for example, in electrical and radio-engineering; it is used wherever an unchangeable metal of high electro-conductivity and resisting all chemical reagents is required. From the vaults and safes gold will come to plants and laboratories as an eternal metal.

RARE DISPERSED ELEMENTS



The earth's crust consists of scores of chemical elements. Only 15 of these are relatively abundant and usual and we can find them in the composition of most rocks; the others are found more rarely.

At the same time some of the rarer elements accumulate in large quantities as ore minerals in ore deposits; others, as for example gold or platinum, of which the earth's crust contains very little, form minutest, hardly visible granules of native metals and, only very rarely, larger nuggets.

But rare as they are they are found in the form of their own independent minerals, be they even so small as to be invisible to the eye. There are other elements, though, of which there is very little in the earth's crust and which do not form their own minerals. The chemical compounds of these elements are dissolved in other, more usual minerals; as salt or sugar are dissolved in water and you cannot tell by the external appearance whether it is pure water or it has something in solution.

It is similarly difficult and not always possible to judge by the external appearance of minerals what chemically dissolved admixtures they contain. While it suffices to taste water to tell whether it is tasteless, salty or sweet, the chemical analysis of minerals is a much more complex affair and it is especially hard to isolate the chemical elements which have hidden themselves in foreign minerals.

Chemical elements have travelled a long and arduous course through melts and solutions before they have combined into solid minerals, i.e., the most stable chemical compounds, in rocks or mineral veins. In their long travels they have suffered many different transformations.

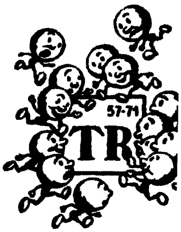
Multiple crystallization of solutions for the division of rare earths in a modern laboratory

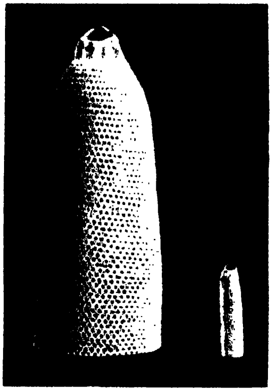
Those that especially resemble each other have gone through everything together and inseparably.

The greater the similarities of the chemical properties of any two elements the harder it is to find a chemical reaction to separate them. Instead of forming their own minerals some rare elements were dissolved and dispersed, sometimes through many minerals or other chemical elements, and we, therefore, call them dispersed elements.

What are these elements, though? You will hardly hear of them in everyday life or even at school chemistry lessons, although with the development of engineering they come more and more into general use.

These elements are gallium, indium, thallium, cadmium, germanium, selenium, tellurium, rhenium, rubidium, cesium, radium, scandium and hafnium. We have enumerated only the most characteristic ones, though the list could be continued.





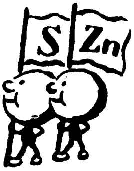
Gas burner mantle containing thorium dioxide

Let us see where and how these rare dispersed elements are found in nature, how man has learned to detect them in other minerals and where they are used.

Here we have before us a yellowish-brown mineral which, when broken, forms perfectly smooth shiny surfaces. This mineral is rather heavy and hardly resembles an ore, though it is an ore. It is known as zinc-blende or sphalerite.

Its composition is very simple: for each atom of zinc there is an atom of sulphur. But this is only the basic background; these are only the main constituents. The composition of zinc-blende only seems simple. Whereas our sample is yellowish-brown, other samples of the same mineral may be brown, dark-brown, black-brown and even altogether black; in the last case they have a real metallic lustre.

What is the matter then?



It appears that the dark colour of zinc-blende is due to an admixture of iron sulphide which is dissolved in it; zinc-blendes which do not contain iron are nearly colourless or are yellowish-green or light-yellow. The more iron the darker the zinc-blende. This means that the colour of this mineral is a true index as regards iron. Studies of the internal structure of zinc-blende by X-rays have shown that the separate particles of zinc and sulphur are so arranged in it that each atom of zinc is surrounded by four of sulphur and each atom of sulphur by four of zinc.

What has happened is that iron has taken the place of some of the zinc atoms and has given the zinc-blende its colour; furthermore, the iron atoms have arranged themselves quite uniformly; one atom of iron has taken the place of either every 100th atom of zinc, or every 50th, or every 30th, 20th, 10th. . . . And this is where the good host—zinc—turned to iron and said: "Aren't you taking too much room in my house?" Though there is much more iron than zinc in nature the former can replace the latter in zinc-blende only to a certain extent; this peculiarity scientists call limited mixing ability.

This example can be used for another interesting comparison; just as a mouse or a bear would never look for shelter in a foxhole because it is too large for the former and too small for the latter, and can only be used by animals of about the size of a fox, so can zinc in sphalerite be replaced only by the elements whose atoms are close in size to those of zinc.

Don't you take up too much room in my house?
Zn
Fe

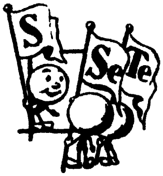
Cadmium, gallium, indium, thallium and germanium are some of the rare elements we find in zinc-blende. . . . Not only zinc, however, but sulphur, too, is able to play host (though to a much lesser extent) to two other rare dispersed elements—selenium and tellurium.

As you see, the composition of zinc-blende turns out much more complex than it appears at first sight. Almost the same can be said of the so-called grey copper ores, of copper pyrite (chalcopyrite) and of many other minerals.

But geochemists have discovered additional regularities: it appears that the iron-rich black zinc-blendes hardly ever contain any cadmium, but they are rich in indium and sometimes in germanium; they have also found that gallium accumulates mainly in light-brown zinc-blendes and cadmium in honey-yellow sphalerite.

The dark-coloured varieties are usually richer in selenium and tellurium. This shows that chemical elements do not equally make

Selenic department at a plant



friends indifferently, and what "roomers" may be allowed to take the place intended for zinc depends on various conditions and different neighbours.

Detection of rare dispersed elements is no easy matter and requires special methods. Their high value forces man to look for them even when their content is very low. Conventional chemical analysis with its most perfect methods and most sensitive chemical reactions is now supplemented by spectroscopic and roentgenochemical methods of analysis.

Without requiring complex chemical separations they are capable of showing at once what other chemical elements and in what quantities the mineral contains. Zinc-blende that contains only 0.1 per cent indium is no longer a zinc, but an indium ore, because even with this meagre content the little indium is of greater value than all of the zinc contained in the mineral.

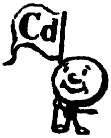
But why have these rare dispersed elements attracted so much attention? Why this interest in them? What makes them so valuable? The main reason is their specific uses. It is the peculiar, special prop-

Testing tungsten filament for electric bulbs. Top: Silhouette of a 60 watt bulb filament magnified 80 times. Centre: Second spiral coil. Bottom: Human hair for comparison erties which either the metals themselves their compounds possess.

Thus thorium oxide, when heated, sheds a brilliant light, and this property has found its application in Auer's incandescent mantles.

Rubidium and cesium are used in mirrors which easily emit electrons, and this makes them indispensable in photocells.

Let us trace the uses of the rare metals or their compounds produced from the zinc-blende just described.



Cadmium.... A light-grey, comparatively soft and fusible metal; melts at 321° C. But suffice it to alloy one part of metallic cadmium with one part of tin, two parts of lead and four parts of bismuth (each of which melts at a temperature above 200° C.) to produce an alloy which is known as Wood's metal and which melts at only 70° C. Just think of it! If you make a tea-spoon out of this alloy and begin to stir your hot tea with it the spoon may melt, and you may find a layer of liquid metal on the bottom of your cup. If you combine the same four metals in different proportions you will produce the Lipowitz alloy which melts at only 55° C. With this molten metal you could not even burn your hands.

Fusible metals are used in many branches of industry. There is a metal which can be melted by only being held in the hand, and it is a pure metal and not an alloy. It is gallium, one of the rare dispersed metals found in zinc-blende (gallium is found, besides, in micas, clays and in some other minerals).

Gallium melts at only 30° C. and after mercury, which melts at −39° C., it is one of the most fusible metals that successfully replaces mercury; mercury vapours, as is well known, are very poisonous, which cannot be said about gallium. Gallium, like mercury, can therefore, be used in the manufacture of thermometers; but while we can measure temperatures over a range of from −40° C. to 360° C. by mercury thermometres, because mercury begins to boil at this point, with gallium thermometres we can measure temperatures from 30° C. to the point of glass softening, i.e., between 700 and 900° C., and if we take quartz glass we can

Cow's hooves eaten out by selenium found in the grass grown in polluted soil measure temperatures up to 1,500° C., since the boiling-point of gallium is 2,300° C.

If we use special fireproof glass for such thermometers we can measure the temperatures ,of flames and of many metals in the molten state.

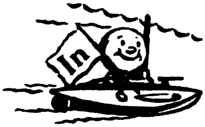
Incidentally, gallium has one more interesting peculiarity. Like ice which is lighter than water and therefore floats on the surface of water, solid metallic gallium is also lighter than molten gallium and can therefore float on the surface of liquid gallium.

This rare peculiarity is inherent also in bismuth, paraffin and pig iron. All other substances sink in their own melt.

But let us come back to cadmium. In addition to yielding valuable fusible alloys this metal is also used for the tramways.

Have you ever seen an old trolley bow? What a deep trough is formed in it as a result of constant friction against the wire! The tram wire against which the bow rubs wears similarly.

And here we find that suffice it to add only one per cent cadmium considerably to reduce the wear of the wire. Cadmium is also used in the production of stained glass for signal lights. The addition of cadmium sulphide to glass colours the latter a beautiful yellow, while cadmium selenide colours it red.



The use of indium is no less interesting than that of cadmium.

It is well known that copper-containing alloys corrode rapidly in salt sea-water. And yet it is not always possible to replace these alloys by chemically stabler substances which are required for submarines and hydroplanes. It appears that an addition of a very small amount of indium to these alloys considerably increases their resistance to the chemical action of salt sea-water.

The addition of metallic indium to silver greatly enchances its lustre, i.e., its reflective ability. This property is utilized in the production of mirrors for searchlights, since the indium contained in the mirrors appreciably increases their power.

Selenium, a rare and dispersed element and sulphur's closest relative, usually found in small amounts in sulphide ores, possesses most unexpected properties.

The electroconductivity of selenium varies with its illumination. This property of selenium is used in the techniques of transmitting images by telegraph and radio. It serves as the basis of many automatic controllers which register light and dark objects moving on conveyers. Finally, accurate illumination measurements have become possible only because of selenium.

Selenium finds another important application in the production of pure colourless glass. Glass is usually made from quartz sand, lime and alkali (soda or sodium sulphate). The sand used must be as pure as possible, and especially free of iron because iron imparts to glass the greenish shade we see, for example, in bottle glass.

It takes very little iron to impart this colour to glass. Window-panes require clean colourless glass; even better glass is needed for spectacles, while optical instruments—microscopes, binoculars and telescopes—require absolutely flawless glass. If we add sodium selenite to molten glass the selenium will interact chemically with the iron, will extract the latter from the molten glass resulting in fine colourless glass.

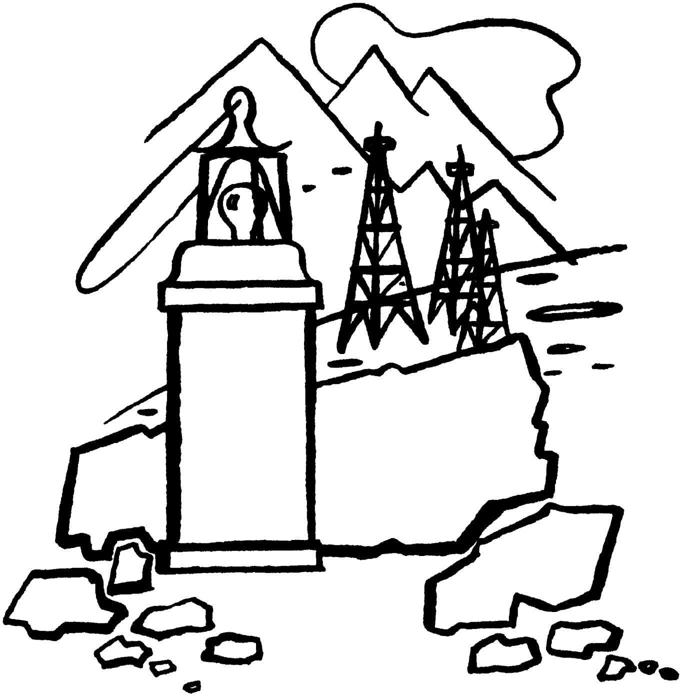
The glass used in the production of special optical instruments, high-magnifying binoculars and powerful cameras must possess a number of other special properties. These properties can be produced by the addition of small amounts of germanium dioxide.

Germanium is one of the rare dispersed elements which, like selenium, is present in small amounts in certain varieties of zinc-blendes. It is also found in some grades of coal.

Now we know how the rare dispersed elements behave in minerals and in ores. We have learned about some of the properties of these unusual metals and about their peculiar uses.

The importance of these uses explains why geochemistry devotes so much attention to the rare dispersed elements.

PART THREE



HISTORY OF THE ATOM IN NATURE

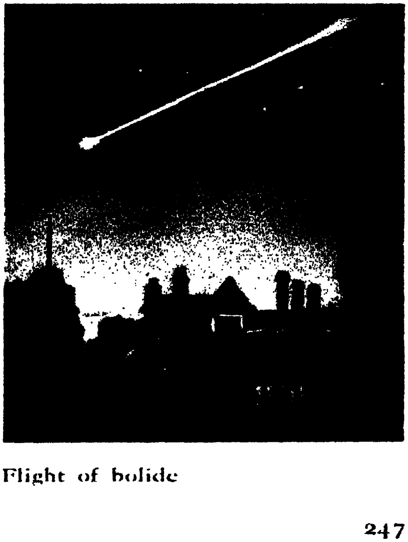
METEORITES—HERALDS OF THE UNIVERSE

It is a dark moonless night. The last gleams of evening twilight have faded. The stars shine brightly in the infinite depths of the firmament, sparkling and twinkling iridescently. The noise in the villages has gradually died down. Nothing stirs in the stillness of the night and only a light breeze is barely heard rustling in the trees.

Suddenly everything is illumined by a bright and, as it were, flickering light. A fire-ball rushes across the sky scattering sparks and leaving a barely luminous, misty trace. The fire-ball is extinguished before reaching the horizon as suddenly as it appeared, and everything is enveloped in the darkness of the night again. But several minutes later sharp sounds like explosions or thunder of heavy artillery pieces are heard. This is followed by a roar, a crackle and a prolonged, gradually fading rumble.

Some of our readers may have witnessed a similar phenomenon. But what is it? What is this fire-ball and where has it come from?

In addition to the nine major planets— Mercury, Venus, the Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto*—a large number



Flight of bolide

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* The planets are named according as their distances from the Sun increase.

M cam and the earth's orbit

of small planets or asteroids move around the sun in interplanetary space. More than 1,500 asteroids are known today; of these Ceres is the largest with a diameter of 770 kilometres while the smallest— Adonis has a diameter of only one kilometre. There are undoubtedly innumerable other smaller asteroids. Their diameters are measured by metres and even centimetres. These are essentially no longer planets but rather fragments of boulders or stones and small granules which can be put on the palm of the hand. They are, certainly, not planets. We could not see them from the earth even through the most powerful telescopes. We call them meteoric bodies; none of them have a regular spherical form.

Most of the large asteriods move around the sun, each in its own definite orbit in the space between the orbits of Mars and Jupiter. Here they form the so-called "asteroid zone." The orbits of an enormous number of small asteroids or meteoric bodies are outside this zone. They cross the orbits of the large planets including that of our earth. While moving around the sun the earth and a meteoric body may find themselves simultaneously at the intersection of their orbits. It is at this moment that the meteoric body comes flying into the atmosphere of the earth causing the appearance in the sky of a fire-ball called a bolide.

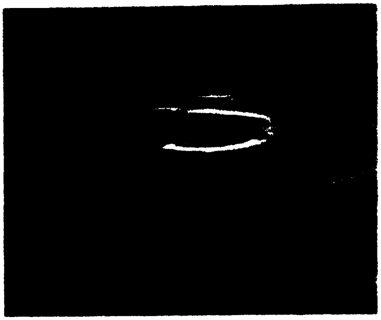
In approaching the atmosphere of the earth the meteoric body may be moving in interplanetary space in a direction opposite to that of the earth. In this case it may develop the extraordinary speed of up to 70 kilometres per second or even more. If the meteoric body is moving in the same direction as the earth, i.e., it is either "catching up" with the earth or "being caught up" by it, its initial speed is approximately 11 kilometres per second. But even this slowest rate is very high; it is many times the speed of a shell or a bullet as they leave the gun.

Owing to this high speed (or as it is called cosmic speed) the meteoric body that has come into the atmosphere meets with a strong resistance of the air. Even at an altitude of 100 to 120 kilometres where, as we know, the atmosphere is extremely rare the meteoric body encounters such great resistance due to its enormous speed that its surface is heated to several thousand degrees and becomes luminescent. The air surrounding the meteoric body is also heated. It is at this moment that the speeding fire-ball—bolide—appears in the sky. This fire-ball is the hot gaseous shell enveloping the meteoric body. Contrary streams of air precipitately break the continuously melting substance off the surface of the meteoric body and spray it in minutest drops. Hardening in the shape of globules these drops form, as it were, a smoky trace, which the bolide leaves behind.

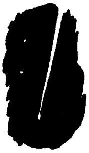
At an altitude of about 50 to 60 kilometres, where the atmosphere becomes already sufficiently dense for the propagation of sound waves, a so-called ballistic wave is formed around the meteoric body. This is a dense layer of air which precedes the meteoric body. Upon reaching the earth's surface the ballistic wave produces the roar and rumble which are heard several minutes after the disappearance of the bolide.

As the meteoric body precipitately penetrates into the ever denser lower layers of the atmosphere it meets with the rapidly increasing resistance of the air. Its motion is retarded and at an altitude of about 10 or 20 kilometres it loses its cosmic speed. The meteoric body gets "stuck," as it were, in the air. This part of its path is called the "region of delay." Here the heating and disintegration of the meteoric body ceases. If it has not fully disintegrated the molten layer on its surface quickly cools, hardens and forms a crust. The hot gaseous shell around the meteoric body disappears. The bolide, which flew across the sky, disappears together with it. The remnant of the meteoric body covered by the formerly molten crust drops nearly vertically after the region of delay, subject to the attraction of the earth. This piece of meteoric body which has fallen on the earth is called a *meteorite*.

The brightest bolides can be discerned even in the day-time in the full light of the sun. Particularly



Photograph of a 3-shaped trace of a bolide observed on September 24, 1948 well seen are the smoke traces which the bolide leaves behind. These traces can be observed for periods lasting many minutes and even more than an hour.



Under the influence of strong air currents in the upper layers of the atmosphere the trace of the bolide, rectilinear in the beginning, gradually curves. Like a legendary giant serpent it stretches across the sky and disappears by breaking up into small fragments.

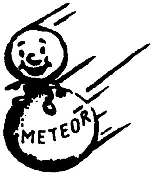
It is precisely the bolides and the traces they leave behind that have given rise to popular legends about flights of fiery serpents and the fairy-tale about the flying dragon.

Bright bolides appear rather rarely. But many of our readers have probably seen *meteors* or, as they are also called, "shooting stars."

Meteors are formed from very small meteoric bodies weighing fractions of a gram which come flying into the atmosphere from interplanetary space. Such minute meteoric bodies completely disintegrate in the atmosphere and do not reach the earth's surface.

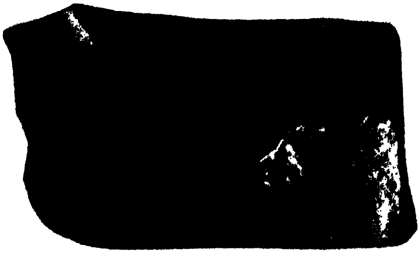
We shall now make a closer acquaintance of meteorites, these heralds of the universe, these strangers from interplanetary space.

The Mineralogical Museum of the U.S.S.R. Academy of Sciences in Moscow has the country's largest and the world's best collection of meteorites. The collection includes many rare or singular meteorites. In the numerous show-cases of the large light hall of the museum the visitor can see wonderful samples of stones many of which are described in this book. They surprise the visitor by their diverse and at times very brilliant colours. But in addition to these attractive stones special show-cases display monotonous gray, brown and black stones and pieces of partly rusted iron. What are these unattractive exhibits? Why, these are the meteorites. For a long time, for thousands of millions of years they had travelled in space and at last, when they met the earth, their wandering ceased.



The meteorites represent the *only unearthly substance* which we can study in our laboratories directly by using up-to-date integrated methods of research and complex apparatus. We can hold the meteorites in our hands, determine their chemical and mineralogical composition, and study their intricate structure and physical properties. They open before us remarkable pages from the history of the universe and the evolution of celestial bodies. They can tell us about many most interesting and wonderful phenomena occurring outside our earth. There is a great deal that is as yet unknown about meteorites and some of their interesting features have not yet been fully explained. However, the studies of meteorites become more profound with each passing year and our knowledge of them is growing ever more complete.

The main task facing the scientists, who are studying the meteorites, is to ascertain the conditions under which they are formed and their subsequent history.



The Kuznetsovo stone meteorite weighing more than 2.5 kg. It fell in Novosibirsk Region on May 26, 1932

Meteorites are divided into *irons*, *stones* and *stony-irons*. Iron meteorites consist of an iron-nickel alloy. They fall much more rarely than stone meteorites. Thus an average of only one iron meteorite falls for every sixteen stone meteorites. Stony-iron meteorites fall still more rarely.

Here we have a black irregularly shaped fragment. This is the Kuznetsovo stone meteorite* which fell in western Siberia on May 26, 1932; it weighs a little over $2\frac{1}{2}$ kg. and is covered all-around by a black fused crust. A small split on the meteorite shows its internal ash-gray substance.

It hardly differs from terrestrial rocks externally. But if you examine the fracture carefully you can see numerous minute sparklets dispersed in the meteorite's substance. These are inclusions of ferro-nickel (iron and nickel alloy). In these inclusions you can see bronze-yellow sparklets; these are a mineral, known as troilite, a chemical compound of iron and sulphur. In addition to troilite we encounter inclusions of another, lighter mineral, which is a compound of iron and phosphorus and is called schreibersite.

The fracture shows that the fused crust which covers the meteorite

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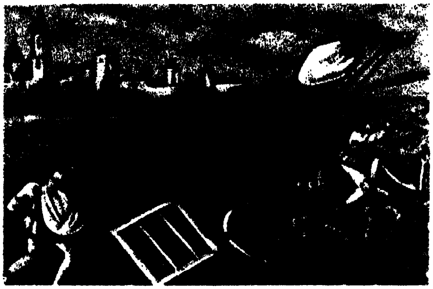
* Each meteorite is named after the populated point closest to the location of its fall.



Fall of a meteorite in Switzerland (after a 15th-century drawing)

is very thin; it is only about a tenth of a millimetre thick. The attention of the visitor is attracted by peculiar now round and now somewhat oblong dents on the surface of the meteorite resembling traces of fingers. These dents are called *regmaglypts*. They are formed on meteorites as a result of the action of separate heated gaseous streams during the movement of the meteoric body through the atmosphere at cosmic speed. The fused crust and the regmaglypts are the principal signs of meteorites.

And here we have another stone meteorite. It is half-split; the point of fracture shows its internal substance which is as black as its fused crust. This is the so-called Staroye Boriskino carbonaceous chondrite which fell in Orenburg Region on April 20, 1930. This meteorite also has other features of which we shall learn later.

Next to this meteorite we see a stone meteorite nearly all white both inside (at the point of fracture) and outside (colour of the fused crust). This meteorite known as the Staroye Pesyanoye fell in Kurgan Region on October 2, 1933.

More than a dozen separate stones weighing a total of about 3.5 kg. were found after the fall of this meteorite. This meteorite is very brittle. It crumbles easily even when lightly touched. It is surprising that so brittle a meteorite could have overcome the enormous resistance of the terrestrial atmosphere without crumbling into sand as it rushed through the atmosphere at cosmic speed. The point is, however, that its region of delay was high above the earth in a layer of very rare atmosphere.

We have made the acquaintance of samples of meteorites which show their typical signs and the differences in the colour of their internal substance.

Let us continue examining the meteorite collection. In the adjacent show-case we see groups of stones of different sizes and irregular shapes. The show-case bears the inscription: "Meteorite Rains."

Humboldt and Bonpland observe a meteoric rain in South America in 1799

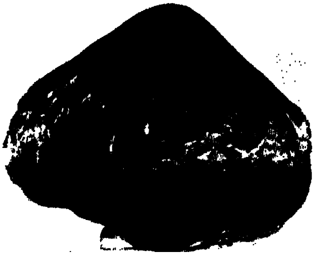
Meteoritic crater in the State of Arizona (U S A.). Diameter of crater—1,220 metre
depth—about 180 metres

It appears that in moving through the terrestrial atmosphere at cosmic speed meteoric bodies nearly always break up into separate parts which are dispersed over the earth's surface covering an area of dozens of square kilometres. The meteoric bodies usually break up before reaching the region of delay where the resistance of the air increases especially sharply. Owing to the irregular shape of the meteoric bodies the pressure of the air which reaches enormous values is distributed unequally along their front surface and the latter breaks up.

There had been cases of real stone rains after which many thousands of separate small meteorites were collected. The most abundant meteorite rain fell near Holbrook, the U.S.A., on July 19, 1912. Fourteen thousand stones weighing a total of 218 kg. were collected here on an area of about 4 sq. km.

In the show-case we see the stones from the Pervomaisky Posyolok meteorite rain. This was one of the most abundant meteorite rains in the U.S.S.R. It fell in Ivanovo Region on December 26, 1933; 97 stones weighing a total of about 50 kg. were found on an area of nearly 20 sq. km.

School children took an active part in collecting this meteorite rain which fell in winter. Separate meteorites went through the snow and were retained on the surface of the congealed ground. This made it possible to collect the meteorites in the fields without any difficulty the following spring, as soon as the snow had melted.



The Karakol stone meteorite weighing about 2.8 kg. It fell in Semipalatinsk Region in May 9. 1840. The meteorite is conically-shaped and looks like a war-head

Next to the stones of the Pervomaisky Posyolok meteorite rain we see the stones of another, so-called Zhovtnevy Khutor, meteorite rain which fell in Stalino Region on October 9, 1938. These stones are noted for their large size, the largest of them weighing 32, 21 and 19 kg., the total weight of the 13 collected stones being 107 kg.

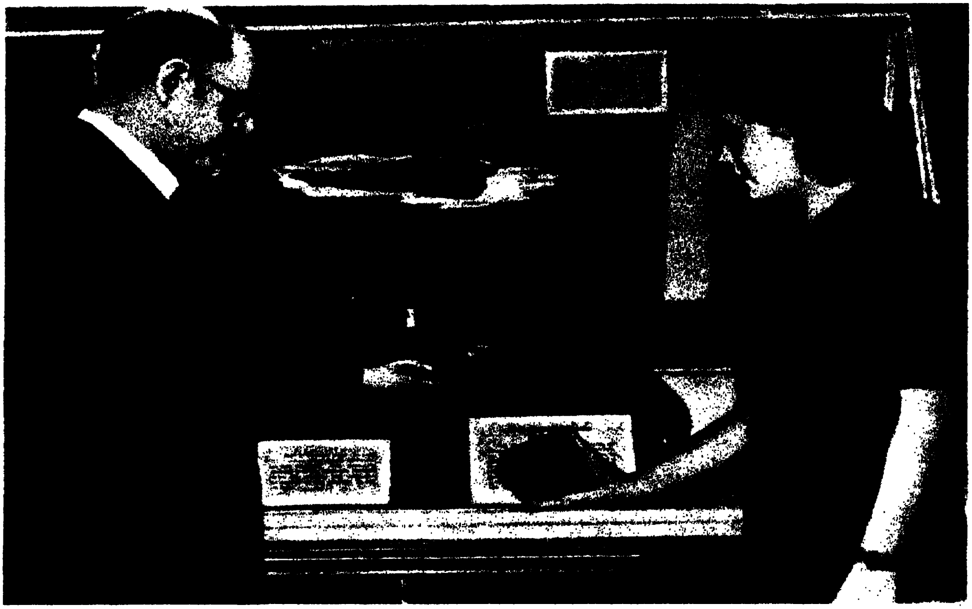
The stones of another meteorite rain, known as the Pultusk meteorite rain, which fell in Poland on January 30, 1868, are also interesting. 3,000 stones were collected after this rain.

In the next show-case we see side by side two interesting meteorites: a giant and a dwarf. One of them weighs 102.5 kg., the other, the size of a nut, weighs only 7 grams. These meteorites fell simultaneously in the Tatar A.S.S.R. on September 13, 1937, about 27 km. apart. Fifteen more stones weighing a total of about 200 kg. were collected here in addition to these two meteorites.

Let us proceed to the next show-case. Here we see samples of meteorites which have typical form. The most usual form is the fragmentary. But here is a meteorite that looks like a war-head. It is the Karakol stone meteorite which fell in Semipalatinsk Region on May 9, 1840. It weighs about 3 kg. This meteorite acquired its conical shape as a result of the grinding action of the terrestrial atmosphere during its movement through the latter at cosmic speed. It fell on the earth without breaking up in the atmosphere.

Next to this meteorite we see another one; it is also a conically-shaped iron meteorite called Repeyev Khutor. It fell in Astrakhan Region on August 8, 1932, and weighs more than 12 kg.

Our attention is attracted by the next meteorite. Its shape resembles



The meteorite which fell on September 29, 1938. It went through the roof of a garage and the top of an automobile and dropped on a seat. Weighs 1,814 grams

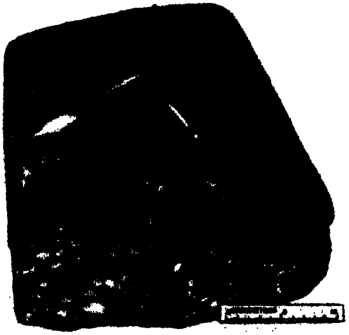
an enormous crystal. This is the Timokhina stone meteorite which weighs about 49 kg.; it fell on the territory of Smolensk Region on March 25, 1807. The meteorite has acquired its form as a result of the initial break-up of one meteoric body into several parts during its movement through the atmosphere at cosmic speed.

Studies have shown that stone meteorites can split along their smooth surfaces like lumps of sugar. This is explained by the properties of their internal structure and mineralogical composition. We see that in many other meteorites of the stone class, including some of the stones of meteorite rains, separate surfaces are also flat and smooth.

The largest meteorites are displayed on special stands. The largest of these, a sample of the Sikhota-alin iron meteorite rain weighs nearly two tons (1,745 kg.). The meteorite attracts our attention by the very interesting structure of its surface. It has sharply pronounced oblong regmaglypts directed radially towards the central part of its wide surface. The regmaglypts show how separate heated gaseous streams flowed past the meteorite during its movement through the atmosphere at cosmic speed.

Three more large samples of the same Sikhota-alin rain weighing 500, 450 and 350 kg. respectively lie next to this meteorite.

The Boguslavka iron meteorite, which fell in the Far East on October 18, 1916, is also remarkable. It consists of two pieces weighing 199 and 57 kg. respectively. This meteorite broke up in its motion through the air.

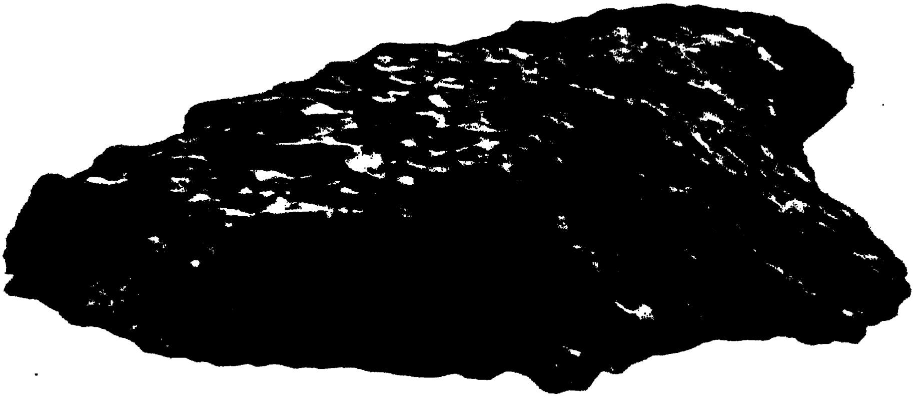


The Timokhina stone meteorite weighing close to 49 kg. It fell in Smolensk Region on March 25, 1807. The meteorite has a multi-sided form which resembles a crystal

And here is another very large stone meteorite named Kashin; it fell on the territory of former Tver Region on February 27, 1918, and weighs 127 kg.

The next show-case brings us to the end of our meteorite excursion. In this case we see a large meteorite cut in halves; originally it weighed more than 600 kg. Both cut surfaces have been polished and now show its remarkable internal structure. It looks like an iron sponge the cavities in which are filled with a transparent glassy greenish-yellowish substance—a mineral known as olivine. It is the first of the preserved meteorites in our country given the name of pallas iron. This meteorite belongs to the class of stony-irons (pallasites). The meteorite was found in Siberia in 1749 by a blacksmith named Medvedev. In 1772 the meteorite was brought to the Academy of Sciences in Petersburg by Academician P. Pallas. There it was studied by E. Khladny, well-known scientist and corresponding member of the Academy. The results of his studies were published in a special book in Riga in 1794. In this book he was the first to prove the unearthly origin of this lump of iron, i.e., its appurtenance to meteorites, and the possibility of meteorites' falling on the earth.

E. Khladny



The largest meteorite from the Sikhota-alin iron meteorite rain which fell in the Far East on February 12, 1947. The meteorite weighs 1,745 kg.

The Boguslavka iron meteorite; fell in the Far East on October 18, 1916. It consists of two parts weighing 199 and 57 kg.

At that time Khladny's inferences were criticized and ridiculed by West-European scientists. They did not believe the fall of meteorites possible and thought the reports of eyewitnesses to have been inventions. But about ten years after the publication of Khladny's book an abundant meteorite rain fell near the town of L'Aigle, France, on April 26, 1803; close to 3,000 stones were gathered in after that rain. Numerous inhabitants saw this meteorite rain. Following this the scientists of Paris, as well as other scientists of Western Europe, could not help acknowledging the existence of meteorites.

The foregoing shows that Russia was the birth-place of the science of meteorites—meteoritics.

The aforesaid large meteorites in the collection of the U.S.S.R. Academy of Sciences are not the very largest. The largest meteorite in the world is the Goba iron meteorite found in West Africa in 1920. It weighs close to 60 tons and has the shape of a rectangular slab 3 × 3 × 1 metres in size. The meteorite is still located where it was found and is exposed to the disintegrating action of the atmosphere.

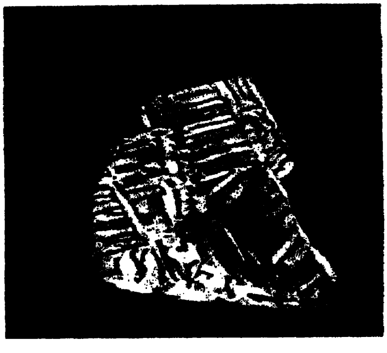
The Pallasovo Zhelezo meteorite found south of Krasnoyarsk in 1749. The picture shows grains of olivine in metallic iron

There are also other iron meteorites weighing 33.5, 27 and 15 tons. The largest stony meteorite weighs about one ton. It fell in the U.S.A. in 1948.

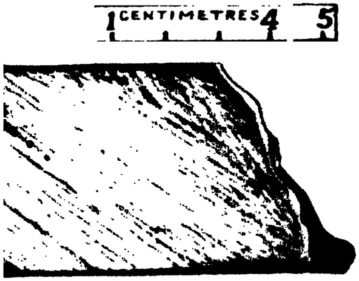
Now let us examine the internal structure of meteorites.

In a separate show-case we see specially arranged samples. Here is an iron piece with a polished surface and a mirror-like lustre. Next to it lies another sample whose polished surface has been treated with a weak acid solution. On this surface we see a wonderful pattern of interweaving lines and fine shiny borders. This pattern is a result of the unequal pickling action of the acid.

The point is that the iron meteorites are not uniform in their mass. They are composed of separate plates from a fraction of a millimetre to two and more millimetres wide. These plates consist of iron with a small admixture of no more than seven per cent nickel. Because of this the polished surfaces of the plates are acted upon by the acid and after pickling become rough and lustreless. Contrariwise, the shiny narrow lines bordering these plates consist of iron with a large admixture of about 24 to 25 per cent nickel.



Widmanstätten figures on the etched surface of a plate cut out of the Chebankol iron meteorite



Neumann lines on the etched surface of a plate cut out of the Boguslavka iron meteorite (see picture on page 258)

Owing to this they resist the action of the acid solution and after pickling remain as shiny as ever. The pattern obtained on the pickled plates of iron meteorites is known as *Widmanstätten figures*, named after the scientist who had first discovered them.

The iron meteorites which show Widmanstätten figures are called *octahedrites* because the plates which form the figures are arranged along the sides of a geometric figure that has eight sides and is called an octahedron.

Not all iron meteorites show Widmanstätten figures after pickling. Some pickled surfaces of iron meteorites show fine parallel lines called *Neumann lines* after the scientist who discovered them.

The meteorites showing Neumann lines contain the least nickel (about five to six per cent). They are monocrystals in their entire mass, i.e., single crystals of the cubic system with six sides, and are called hexahedrons. The iron meteorites which show Neumann lines are, therefore, called *hexahedrites*.

We encounter one more type of iron meteorites, known as *ataxites*, which means "devoid of order." These meteorites contain the most nickel (more than 13 per cent) and when pickled their polished surfaces show no definite pattern.

Stony meteorites also have a very interesting structure.

Here is a fragment of a meteorite in a fracture of which we can see perfectly regular globules, resembling shot, even with a naked eye. Under a microscope the entire surface of the

Chondrules in the fracture of a stone meteorite (chondrite). Saratov fracture in some meteorites seems covered with these globules whose size is a fraction of a millimetre and even smaller. The globules are called *chondrules*, while the meteorites containing them are known as *chondrites*.

The chondrites are the most widespread meteorites and constitute approximately 90 per cent of all stony meteorites. The chondrules are structures typical only of meteorites. They are never found in terrestrial rock and their presence in an unknown sample may, therefore, serve as a reliable indication that this sample is a stony meteorite. Scientists have come to the conclusion that the chondrules are rapidly cooled drops of molten substance of the meteorite and that they were formed at the same moment as the meteorites.

In addition to the chondrites there are also stony meteorites which do not contain any chondrules and which are called *achondrites*; true, these achondrites are much fewer. The fractures of these meteorites show angular fragments of separate minerals cemented by the fine-grained principal mass of the meteorite. The structure of these meteorites very much resembles that of terrestrial rock. There are still other, rarer types of stony meteorites with their own peculiarities, but we shall not dwell on these.

Now let us examine the composition of the meteorites. The following table shows the chemical composition of meteorites of different classes.

Average Chemical Composition of Meteorites of Different Classes

Chemical elements	Average chemical composition		
	Irons	Stony-irons	Stones
Iron	90.85	49.50	15.6
Nickel	8.5	5.00	1.10
Cobalt	0.60	0.25	0.08
Copper	0.02	—	0.01
Phosphorus	0.17	—	0.10
Sulphur	0.04	—	1.82
Carbon	0.13	—	0.16
Oxygen	—	21.30	41.0
Magnesium	—	14.20	14.30
Calcium	—	—	1.80
Silicon	—	9.75	21.00
Sodium	—	—	0.80
Potassium	—	—	0.07
Aluminium	—	—	1.56
Manganese	—	—	0.16
Chromium	—	—	0.40

In the table we see all familiar chemical elements and not a single new one. Is it possible that the meteorites, these strangers that have come to us from distant spaces of the universe, do not really have any new chemical elements, any more wonderful chemical elements than the ones we know on earth? Is it possible that in the distant parts of interplanetary space there is nothing new, nothing unlike the things we have on our earth?

We are actually all very close relatives

As a matter of fact the most accurate and most painstaking analyses of the most diverse meteorites conducted over a period of more than 100 years by a large number of scientists have shown that they *do not contain a single chemical element unknown on the earth.* At the same time we find in the meteorites practically all of the chemical elements we know on the earth though most of them constitute a very negligible part detected only by fine spectral analysis.

In recent years scientists have obtained one more important confirmation of the common origin of these celestial bodies.

Scientists have studied the isotopic composition of a number of chemical elements of both terrestrial and meteoritic origin. They have found also in this case *a complete identity of the isotopic composition of the elements.*

The foregoing table shows that the stone meteorites contain mostly the following chemical elements: oxygen (41.0 per cent), iron (15.6 per cent), silicon (21.0 per cent), magnesium (14.3 per cent), sulphur (1.82 per cent), calcium (1.8 per cent), nickel (1.1 per cent) and aluminium (1.56 per cent).

Oxygen is present in the meteorites in combination with other elements forming various minerals (silicates and oxides). Iron is also contained partly in combination with other elements and partly in the metallic phase in the form of these minutest sparklets which we see in the fractures of meteorites and which are spread throughout their mass.

However, the content of chemical elements in separate meteorites may considerably differ from their average composition.

Marshy terrain in the region of the fall of the Tunguska meteorite

Precious metals are found in meteorites in negligible quantities. For example, an average of five grams of silver and gold and 20 grams of platinum are found per ton of meteoritic substance.

Meteorites fall on the earth incessantly. Scientists have estimated that at least 1,000 meteorites fall on our earth annually. However, only an insignificant part of them, about four to five meteorites, are discovered during the year.

The rest of the meteorites which fall into seas and oceans, in polar countries and deserts, in mountainous or wooded regions, away from inhabited areas in general, are never found. They disintegrate under the action of the atmosphere and become part of the soil.

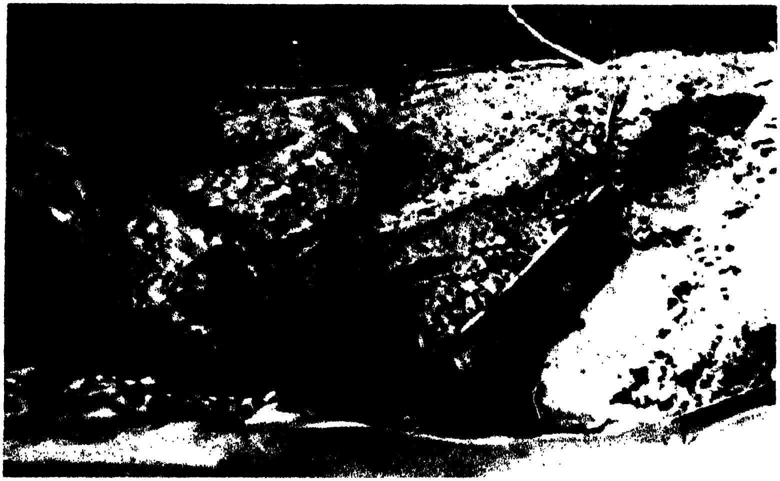
Meteoritic atoms mix with those of the earth. From the soil they get into plants and through the plants, which are used for food, as well as through the animals, which eat the plants and serve as food for man, the meteoritic atoms find their way into man's organism.

We see that not only our earth, but also the organic life on it is closely interlinked with the part of the universe surrounding it.

Scientists have tried to estimate the annual increase in the mass of the earth due to the fall of meteorites. It appears that from five to six tons of meteoritic substance fall on the earth every day.

Thus, the mass of the earth annually increases by about 2,000 tons. This is, of course, a negligible amount even if it is somewhat increased by the settling of atmospheric meteoric dust formed on the earth by the movement and destruction of the meteoric bodies. Academician V. Vernadsky did not believe that the mass of the earth increased. He wrote that while the earth received substance in the form of meteorites and meteoric dust it gave off into the solar system other material particles, atoms, mainly gaseous, and very fine dust. This resulted in a mobile material equilibrium. Academician Vernadsky thus came to the conclusion that we were dealing "*not with accidental falling of separate meteorites, bolides and cosmic dust on the earth, but with a great plane-*

Felled trees in the region of the fall of the Tunguska meteorite



The largest crater, 28 metres in diameter and 6 metres deep at the site of the fall of the Sikhota-alin iron meteorite rain

tary process, with a material exchange between our planet and cosmic space." It is in this process that the inevitable interaction between our planet and the environment, i.e., with interplanetary space, consists.

While the chemical analysis of meteorites has not yielded anything new, though very important inferences about the material unity of the celestial bodies and the earth have been made as a result of this analysis, the study of the mineralogical composition of meteorites has shown their peculiarities.

Meteorites are essentially composed of the minerals which are also abundant in terrestrial rocks. These are olivine and anhydrous silicates: enstatite, bronzite, hypersthene, diopside and augite; minerals of the feldspar group are also encountered.

But many minerals, which are products of weathering, have not been found in the meteorites. Nor have any organic substances been discovered in them.

Characteristic of meteorites is also the absence of minerals of the hydrous silicate group, i.e., minerals containing chemically-combined water. Scientists have made many persistent attempts to find such minerals in meteorites but they have all been of no avail. Only very recently did Soviet scientists discover a mineral of the chlorite group, i.e., a hydrous silicate. It is contained, however, only in the meteorites which belong to the rare type of stony meteorites, the so-called carbon chondrites.

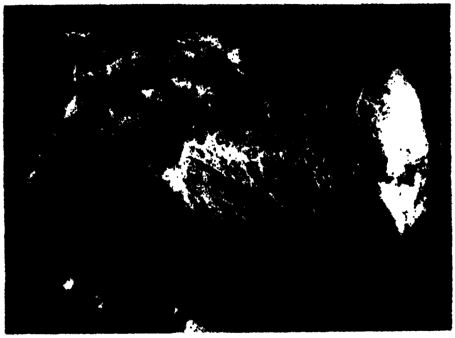
Investigations have shown that the chemically-combined water which forms part of the chlorites constitutes 8.7 per cent of the total weight of the meteorite.

This discovery is of great importance to the solution of our main problem, i.e., the finding out of the conditions under which meteorites arise.

Fragment of a large meteorite from the Sikhota-alin iron meteorite rain

The discovery of minerals unknown on the earth in meteorites is also of great importance. True, the meteorites contain very small amounts of these minerals. Nevertheless, they show that the meteorites are formed under conditions which differ from those under which the earth's crust was formed. The ascertainment of these conditions represents one of the most important problems of meteoritics. The discovery of phenomena of metamorphism in meteorites under which not only the structure of meteorites but also the minerals themselves have changed is of particularly great interest. This metamorphism was due to the heating of the meteorites by the rays of the sun during their numerous approaches to it as they moved in interplanetary space through-

Individual meteorite of the Sikhota-alin iron meteorite rain covered by a fused crust and showing sharply pronounced regmaglypts



Structure of the fused crust of an individual meteorite from the Sikhota-alin iron meteorite-rain; magnified 7 times

out their existence. The detailed studies of the metamorphism of meteorites, especially extensive in recent years, reveal the history of the meteorites, the history of their wanderings in space.

Meteorites also contain radioactive chemical elements. One of these elements is potassium present in stony meteorites in appreciable quantities. Radioactive disintegration of potassium produces argon. We can therefore judge the age of the meteorites by the proportions of argon and potassium contained in them, i.e., we can estimate the time that has elapsed since the formation (hardening) of the meteorites.

Soviet scientists have recently estimated the age of meteorites by argon and potassium. These estimates have shown that the meteorites are from 600 million to 4,000 million years old.

Today we know whence the meteorites come to earth. But when and how the meteorites were formed is still one of the most important problems on which scientists studying the meteorites are now working.

Most Soviet scientists believe that the meteorites and the asteroids are fragments of one or several large celestial bodies (planets) which broke up in the distant past. But this is only a conjecture, a working hypothesis, which requires further thorough studies of meteorites to be confirmed and fully demonstrated. There can be no doubt that the problem of the origin of meteorites, of their role in the formation of the planetary system and of the subsequent development of the latter will find its final solution.

ATOMS IN THE EARTH'S INTERIOR

Several entertaining novels by Jules Verne, George Sand and Academician V. Obruchev describe trips to the centre of the earth, to the inaccessible interior of the world. In other books the fantasy of the writer flies to unknown heights. These books from the fantastic novels of the 17th century all the way to K. Tsiolkovsky's carefully calculated "flights to the moon" lead us to distant, seemingly inaccessible worlds.

These fascinating novels show the inquisitive mind of man who cannot reconcile himself to the fact that he lives on a thin film of earth and that his eye can only see into some 20 or 25 km. of the earth's interior.

In the struggle for expanding and mastering the world man has undoubtedly made great headway in the last 50 years. The ascents to the highest snow peaks frequently made by man out of pure sport were replaced by scientific expeditions of the U.S.S.R. Academy of Sciences aimed at mastering the Pamirs.

Mount Stalin in the Pamirs, 7,495 metres above sea level

The ideas that the higher layers of the atmosphere, which are not reached by the hustle and bustle of the earth or the chemical struggle of the terrestrial molecules, are inaccessible have also receded into the past: Fedoseyenko, Vasenko and Usyskin, Soviet stratonauts, have made the first successful attempts at mastering the altitudes at the peril of their lives.

The flights on stratostats and those of rockets have greatly advanced the knowledge of the spheres where the amount of substance sharply decreases, where one cubic metre of air contains millions of times as few particles as that on the earth's surface.

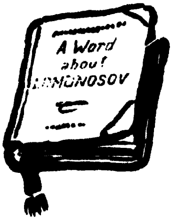
Man is primarily attracted by altitudes and here his achievements are very real; engineering has made enormous progress, and the scientists know this distant and still inaccessible world much better than that which spreads under our feet, i.e., the world of the earth's interior.

We do not know very much about the interior of the earth. Man is attracted to the interior mainly by his struggle for oil and gold. He drills pits and sinks mines which penetrate into the entrails of the earth, but the deepest oil-wells are no deeper than 5 km., while the deepest gold-mine is less than 3,000 metres deep. And this is considered a great accomplishment.

In his pursuit of gold and oil man will, naturally, be able to penetrate still deeper. It is quite probable that the accomplishments of modern engineering will make it possible to break these records by a few more kilometres. But what are these kilometres compared with the earth's radius of 6,377 km.? It is only some 0.001 of it.

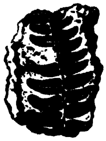
It is quite natural therefore that man cannot reconcile himself to this and that all men of science, from the philosophers of early antiquity to the astronomers of our time, have always been interested in the problem of the internal structure of the earth and in the ways and means of mastering the interior of our planet. Let us at least form a cursory picture of what we know of the earth's interior by taking an imaginary trip from the earth's surface into the interior and let us see what we can find.

* * *



We find the first attempt to describe a trip into the earth's interior in Lomonosov's writings. True, his ideas are scattered through a number of his works, but A. Radishchev in his *Word about Lomonosov* (1790) collected them into a single volume. Ending his famous *Journey from Petersburg to Moscow* Radishchev curiously enough devotes just the last pages of his story about the hard journey over the filthy and bumpy post road to the peculiar trip made by Lomonosov to the centre of the earth and tells us what the scientist might have seen had he descended successively from the earth's surface to ever deeper layers of the earth. We quote this remarkable description:

"...he (Lomonosov) steps with trepidation into the opening and soon loses the sight of the life-giving sun. I should very much like to follow him in his underground trip, to collect his thoughts and state them in the order and in the connection in which they come to his mind. The picture of his thoughts would certainly be amusing and instructive to us.



"In going through the first layer of the earth, the source of all life, the underground traveller finds it unlike the next layers since it differs from the others in its great fertile power. He may conclude from this fact that the earth's surface consists of nothing but animal decomposition and germination, that its fertility, a nutritive and restorative force, takes its source in the indestructible and primary parts of all existence which without changing its essence only changes its appearance, the latter being a matter of accident. In going further the underground traveller sees that the earth is always arranged in layers.

"In these layers he sometimes finds remains of marine animals and of plants and may conclude that the stratification of the earth is a result of the fluidity of waters and that by moving from one part of the earth to another these waters impart to the earth the appearance which it has in its interior.

"Losing sight of this uniform stratification he sometimes imagines it as a mixture of many various layers. He concludes this from the fact that the fierce element of fire by penetrating into the earth's entrails met the resistance of moisture and in its rage stirred, shook, overturned and scattered all that offered it any resistance.

"By stirring up and mixing the heterogeneous, the hot breath of fire gave rise to the attractive force of metals and joined them. There Lomonosov beholds these dead treasures in their natural state, remembers the cupidity and suffering of man and with a heavy heart leaves this dark abode of human greed."

Examining this text we can now say that it fully corresponds to our modern ideas; not a single word of it can be refuted.

But if we try to compare this fantastic picture drawn by a scientist of the 18th century with the picture of our own ideas (which are much closer to reality) about the earth's entrails studied by means of boring tools we shall see the following.

A small derrick invisible from the street was built near Krestyanskaya Zastava in Moscow a few years ago. There was a boring machine in the derrick; this machine was supposed to bore deep into the earth to find out the structure of the ground underneath Moscow.

Working hard and persistently the borers tried to reach a depth of several kilometres. At first they bored through the clays and sands which had been deposited on the Moscow plain by the southern streams of the great glacier that had come from Scandinavia. These were the last paroxysms of the glacial epoch when all of the north European part of the Soviet Union was covered by a continuous coat of snow and ice.

Under these clays came different limestones, then layers of marls and clays again; in some places there were lime skeletons and shells among the limestones, the limestones were replaced by sands with separate coal layers which indicate the coal-field that supplies the central industrial region with its fuel and gas.

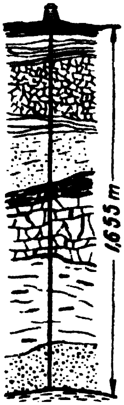
The geologists examined in detail the ancient Carboniferous seas and found that they had been shallow in the beginning, that their shores had been covered by luxuriant vegetation which had grown stormily under the conditions of a humid and hot climate. Later these seas became deeper, waters rushed in from the east and north and broke up the forests and destroyed the vegetation; the luxuriant world of living submarine creatures laid the basis for the coral reefs and banks of shells. It was at that time that the limestones, used in the construction of Moscow houses owing to which Moscow was given the name of "White-stoned," were deposited. The same limestones are also widely used today.

The bore-hole went through the entire complex series of layers deposited during the long Carboniferous epoch, which had lasted many scores of millions of years, and ran into new layers of enormous amounts of gypsum. It went through hundreds of metres of gypsum sediments, through argillaceous layers and through large quantities of water.

These waters were at first saturated with sulphates and later, as the bore-hole reached deeper, they contained ever more salts of chlorine. The bore-hole penetrated into brines containing ten times as much salt as sea-water. These were mainly sodium and calcium chlorides, but there were also many salts of bromine and iodine.

Multi-storied building near Krasniye Vorota in Moscow. Faced with white Moscow limestone

It was no longer a picture of the Carboniferous epoch, but of an older, so-called Devonian epoch. These were disappearing seas with salt-lakes, firths and deserts which had surrounded the seas; the salts deposited on their floors in heavy layers were interspersed with thin layers of silts and dust brought by hurricanes and tornados of the Devonian desert.



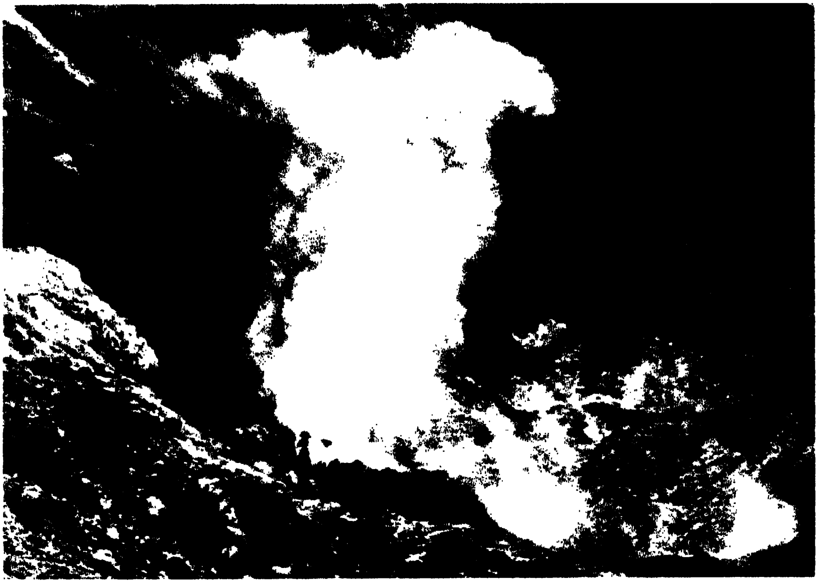
The bore-hole was now 1.5 km. deep. What could we expect now? What could we find under the sediments of the old Devonian seas and what new pictures would the geologist see as he bored another few hundred metres? Intricate conjectures agitated the minds of scientists and daring thought searched for various hypotheses. And then, at a depth of 1,645 metres, they suddenly ran into sands. These were, apparently, the shores of the Devonian sea; the sands signified that land was near. They included separate pebbles of igneous rocks and polished fragments of the seashore. These were already shores, real shores, and after another ten metres the bore-hole reached hard granite.

Thus the boring tool in Moscow for the first time cut into the granite base, the foundation of all Russian land from Leningrad in the north to the Ukraine in the south. Soon new bore-holes in Syzran and further east reached the granite bed at approximately the same depth and confirmed the forecasts made by Academician A. Karpinsky that ancient granite masses underlie the entire surface of our European plain, i. e., the old platform or shield as we know it from the beautiful granite and gneiss cliffs of Karelia in the north and along the banks of the Dnieper and the Bug in the south. The bore-hole went through another twenty metres in hard granite. According to the estimates of geologists these were real granite rocks, the ancient deposits which may be at least 1,000 million years old.

The bore-hole had thus reached the deep granite bed underneath Moscow. But what was further down? What could be expected under these granites? Could another 2,000 metres be bored in order that the depths where the granite masses float may be reached? This question gave rise to stormy controversies.

Some believed that further boring was useless, that many hundreds and even thousands of metres would have to be bored before the hard layers of the granite gneiss platform ended.

Others insisted that the boring be continued in order that the riddle of still greater depths might be solved. The borers encountered enormous



Smoking crater on a slope of a volcano

difficulties, their work growing ever more complicated with each metre; from a depth of nearly two kilometres they brought to the surface beautiful pink hard rocks of granite and gneisses.

It is as yet impossible to reach the deepest layers of the earth because human engineering is still too weak. In order to master deeper zones of the earth other ways and means must be used. This was first suggested by Eduard Suess, young Austrian geologist, in 1875.

He proposed to take a bird's-eye view of the earth from the positions of geology and the already existing geochemistry. Suess tried to outline the essential and more uniform layers of which the earth consists. For this purpose he followed, primarily, in the footsteps of the old philosophers and divided the earth into three simple shells: the air or atmosphere which completely surrounds the earth; the hydrosphere, i.e., the waters and the ocean which cover solid earth and saturate it and, finally, the lithosphere, i.e., the sphere of stone the interiors of which contain the eternally raging fire exhaled by the volcanoes.

He continued this division on the basis of the analysis of the chemical composition of hard rocks.

In 1910 the English naturalist Murray subdivided the layers of the earth into separate shells and named them geospheres.

It was at that time that chemists and physicists, geochemists and geophysicists began their hard and persistent work in order to get a further and deeper insight into the structure of these separate shells or geospheres. The Russian scientist V. Vernadsky and his school posed this problem in its entirety.

Instead of drawing an external picture of the "face of the earth" the geologists and geochemists were confronted with the problem of re-creating all the processes occurring in each geosphere and of painting a complete picture of the internal structure of our planet.

We shall now endeavour briefly to characterize the shells of which our planet consists as they are pictured by geophysics on the basis of studying the behaviour of the resilient oscillations of waves which reach enormous depths and mark the borders of separate geospheres by their reflection.

Scientists now count 13 shells from the inaccessible interstellar space filled with meteors and molecules of hydrogen and helium and separate atoms of sodium, calcium and nitrogen.

The lower border of this layer is at an altitude of about 200 km. Below this begins the stratosphere, and the amounts of nitrogen and oxygen increase. A layer of ozone separates individual parts of the stratosphere. The northern lights go on at altitudes of several hundred kilometres and luminous clouds rise to an altitude of 100 kilometres.

The second layer, which we call the troposphere, begins at an altitude of 10 to 15 kilometres.

This is our atmosphere, the air we are accustomed to with its nitrogen, oxygen, helium and other noble gases, saturated with water vapours and carbon dioxide.

This is followed by a zone of about five kilometres which is called the biosphere, i.e., the sphere of living substance. It also includes the upper portions of the earth's crust and its aqueous shell.

Then comes the aqueous zone known as the hydrosphere. This sphere is composed of hydrogen, oxygen, chlorine, sodium, magnesium, calcium and sulphur.

Mud bed several kilometres long formed by mud streaming out of cracks during the earthquake in Yangi-Kurgan District of Namangan Region (Uzbekistan) on the night of November 3, 1946

The hard shell comes after this; in the beginning it is the well-studied crust of weathering with its acid salts and soil layer; this is followed by the layer of sedimentary rocks—sediments of the old seas, i.e., clays, sandstones, limestones and coal layers. Already at a depth of 20 to 40 km. we encounter a new layer called metamorphic.

Still deeper down are the granites rich in oxygen, silicon, aluminium, potassium, sodium, magnesium and calcium. Somewhere in the interior, at a depth of about 50 to 70 km., they are replaced by basalts with magnesium, iron, titanium and phosphorus which substitute for aluminium and potassium.

A sharp change occurs at a depth of 1,200 km. Here the hard layers are replaced by peculiar melts and the new peridotitic or olivine shell consists of oxygen, silicon, iron and magnesium with heavy metals—chromium, nickel and vanadium.

The studies of earthquake waves registered by sensitive instruments, called seismographs, clearly show that there are shells of different composition in the interior of the earth. The very sensitive instruments invented by B. Golitsyn, Soviet academician, has made it possible to detect not only the waves that travel the shortest route but also those which run around the entire globe and those that are reflected from the borders of layers of the earth of different densities, for example, from the core of the earth. These data serve as weighty arguments in favour of the existence of lithospheric layers. Some scientists believe that an ore shell with accumulations of titanium, manganese and iron runs to a depth of 2,450 km.

A still greater leap in densities is observed at a depth of 2,900 km. where, as it is believed, the central core begins; this core whose properties we do not know as yet in all probability consists of iron and nickel with an admixture of cobalt, phosphorus, carbon, chromium and sulphur.

That is the way geophysicists and geochemists picture the structure of our earth, and each of these layers is characterized by the elements which prevail in its composition. Each of them also has its typical temperatures and pressures.

In this complex and in many respects, perhaps, inexact picture there is still one sphere which invariably attracts our attention. It is the sphere in which we live and which differs from all the other geospheres by its special properties.

It is a zone of 100 km., a zone of chemical life, a sphere of terrestrial chemical processes, a sphere of stormy paroxysms, variations in temperatures and pressures, a sphere of earthquakes and volcanic eruptions, a sphere of disintegration in some places and restoration in others, a sphere of cooling of Plutonic melts, hot springs and lodes and, finally, the sphere of life of man with his stormy aspirations, constant struggle against nature and for nature, the sphere inhabited by millions of species of living creatures, the sphere of new peculiar

Kamchatka. Avacha Bay near the city of Petropavlovsk. Avacha Volcano in the distance

Lake in the crater of the Santorin Volcano (formed about 3,500 years ago), Greek Archipelago

and intricate combinations of chemical molecules, the sphere of life and struggle and quests, the sphere of new processes and new transformations.

This sphere of life is, not without reason, called by geologists the troposphere, i.e., the zone of movement. This zone lives its own complex chemical life, and the processes of construction and combinations of chemical elements in it determine all the fates of our earth in its various geological epochs. It is a zone of purely terrestrial reactions and it is remarkable that though thousands and thousands of celestial stones, meteorites fall on earth and thousands of fragments of cosmic bodies find themselves in the hands of scientists not a single one of them has ever given us at least a piece that might remind us of this stormy zone of life and death on our planet.

It is thus the chemical processes in the interior of our earth appear to man, whose physical existence is limited to a film only several kilometres thick.

But in the slow and stubborn struggle of his genius man constantly expands his knowledge of the world.

We are firmly convinced that both the interior of the earth and the spheres above the clouds will be conquered not only by the scientist's abstract thinking but also by engineering.

We see how the waves of large geophysical instruments penetrate into the interior of the earth by the will of man and reflected there bring us the answer as to the structure of the earth's shells. The enormous explosions made in the Urals and in the south of the country bring us entirely new ideas about this structure. A series of precision machines, fireproof pipes and rods with cutters of super-hard alloys and diamond crowns will easily and with the fabulous speed of hundreds of metres per shift cut into the hard granite, and we are sure it will not be many years before the Moscow bore-holes, which seemed the height of technical accomplishment, will recede into the distant past.

Man will conquer the interior of the earth scores of kilometres deep not only in novels, but in actual life by winning another technical victory over the earth.

There are no limits to cognition of the world! There are no limits to conquests by the human mind!

HISTORY OF THE ATOMS IN THE HISTORY OF THE EARTH

More than 100 years ago upon his return from a trip to the then unknown American countries Alexander Humboldt (1769-1859) delivered a series of lectures at Berlin University; in this lecture he attempted to paint before his listeners unusual pictures of the universe.

Subsequently he set these ideas forth in his book entitled *Cosmos*. The word cosmos comes from the Greek and expresses the idea not only of world but also of order and beauty, because in the Greek language this word equally signifies the universe and the beauty of man.*

In Humboldt's exposition the cosmos represented a totality of various facts.

Basing himself on the accomplishments of 19th century science, he endeavoured to explain order by the unity of natural laws and in the picture of the present he wanted to see something more than merely one of the moments in the complex process of the development of the world. He failed, however, because the world in his ideas was still broken up into separate natural kingdoms. Each of these kingdoms had its own representatives with no common bonds between them.

The old classification divided the world into individual cells and separated the minerals, plants and animals from each other by impassable barriers.

The old ideas of the 17th and 18th centuries were still adhered to, the world still appeared immutable and made by the will of God from an enormous number of independent "kingdoms" and, though

A.Humboldt

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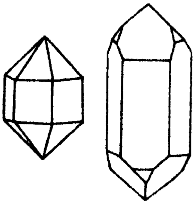
* We know this very well from life because we speak of cosmic worlds and cosmetics.

Portion of solar surface photographed in hydrogen rays

Alexander Humboldt wanted to show that all natural phenomena were interlinked, he was unable to do so because he had no facts, no proofs, no units which he could take as a basis for the relationships existing in the nature that surrounds us.

It is atoms that have proved to be these units, and in our time the picture of the cosmos is painted against an entirely different background. Inexhorable laws of physics and chemistry govern the complicated and long history of the migrations of individual atoms. We have already seen that separate atoms are deprived of their electrons in the centre of cosmic bodies; we have seen a gradual creation of a complex particle of element with the electron-planets rotating around the centre.

We have seen molecules, i.e., chemical combinations, born in a desert world of cooling stars, by interlacing with and being engirded by the rings of these planets. Then ever more complicated structures come into being; ions, atoms and molecules form crystals, these new remarkable elements of the world, elements of a higher order, mathematically perfect and physically beautiful. We can take as an example of this the transparent pure crystal of quartz which even the ancient Greeks had named *crystallos*, i.e., "petrified ice."



We have seen the growth and destruction of beautiful structures of the crystal on the very surface of the earth; we have seen a new mechanical system arise from these fragments—a world of colloids, minutest groups of atoms and molecules. And in this environment it is a new type of complex and large carbon-containing molecules, the type we call a living cell, that proves to be stable.

New laws of development of living substance increasingly complicate the fates of atoms in the course of their history, creating complex clots of myceliums, minutest semi-animals, semi-plants, semi-colloids which we call viruses, hardly visible in ultra microscopes and, finally, the first unicellular organisms which we now well distinguish in our microscope, i. e., bacteria and infusoria.

It is through these historical stages that the atoms of different elements of our world travel, and a history of life can be constructed for each one of them from the moment the first terrestrial particle had cooled all the way up to their migrations in the living cell.

Once upon a time, almost the way we read about it in fairy-tales, a cluster of atoms arose in world chaos and began to emanate electromagnetic waves; the heat movement gradually decreased, as the astronomers say, and the system cooled.

It does not make any difference to us who was the first of the numerous astronomers and philosophers to try and divine the mechanics of this process, nor when it was done. The only thing that matters is that the cluster is formed where the atoms of individual elements come in contact with each other.

We know the composition of this cluster: modern geochemists tell us that it is composed of about 40 per cent iron, 30 per cent oxygen, 15 per cent silicon atoms, 10 per cent magnesium, and 2 to 3 per cent nickel, calcium, sulphur and aluminium. Then come the elements which constitute lesser amounts—sodium, cobalt, chromium, potassium, phosphorus, manganese, carbon, etc. This list shows that the chief chemical elements of which the universe is composed are all stable atoms built according to the laws the evenness of which we have already mentioned.

This intricate cluster consists of nearly 100 types of atoms, with some of them encountered in enormous quantities and others only in billionths of one per cent.

In subsequent cooling the free atom-gases little by little form liquids and coming together as separate molten fiery-liquid drops, go through all the processes to which molten ores are subjected in the blast-furnace.

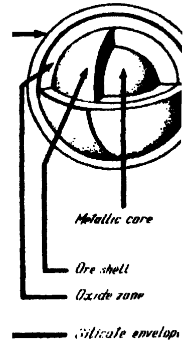
The structure of our planet was unexpectedly divined not by theoreticians, not by geophysicists, but by metallurgists, the people who have learned to smelt metal, to get rid of the slags and to guide the fate of the individual atoms in the heat of the blast-furnace. According to the laws of physics and chemistry the atoms repel each other and the initial melt divides into separate parts. At this time all the chemical

Hot lava erupted on September 6, 1934, forming a lava lake. Sandwich Islands

elements arrange themselves in a definite order. The light, mobile parts rise to the top, and the heavy ones go to the centre.

A metallic nucleus is thus accumulated. A layer of metal sulphides is not infrequently formed above the nucleus with a crust of silicious compounds deposited still higher as a scale or slag. Geophysicists say that all the separate shells or geospheres, of which our earth is composed, correspond precisely to the separate zones, the separate products of smelting in a large blast-furnace.

In the very interior of the earth at a depth of about 2,900 kilometres there is the iron core. Here we have an accumulation of the metals which go along with iron in the blast-furnace; these are, primarily, iron itself and its closest friends and analogues—nickel and cobalt. Here, too, are the elements which chemists call siderophiles or "iron-loving," thereby repeating almost exactly the words of the alchemists who were ridiculed by the scholastics of the 18th century. The siderophiles include platinum, molybdenum, tantalum, phosphorus and sulphur which are undoubtedly akin to iron. Thus do we picture the composition of the deepest part of our earth.



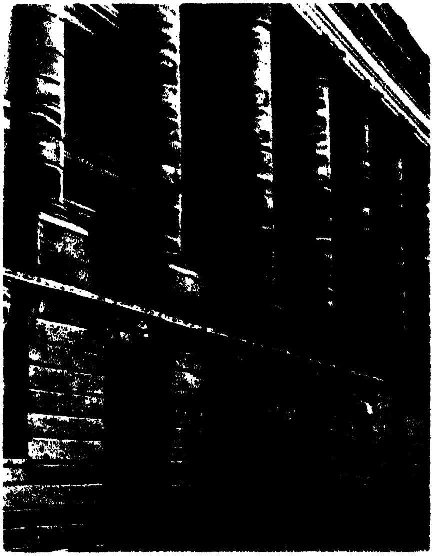
Above the core, at a depth of probably 1,200 to 1,300 kilometres, there is another zone; controversies as to its chemical composition raged for a long time, but there is no doubt that it is the zone which we know very well from smelting copper or nickel. These are metal sulphides. And it is not without reason that enormous zone of the earth's crust 1,500 kilometres thick is frequently called the ore shell.

This is the place where sulphides of copper, zinc, lead, tin, antimony, arsenic and bismuth must accumulate. The majority of them, however, are constituents of the sulphide minerals, which we also find in the more superficial zones of the earth's crust.

Then comes the very "scale," or oxide zone. It is also divided into separate zones. In the interior we have vast accumulations of rocks rich in silicon, magnesium and iron. This is a zone of which we began to get a notion only after we had studied the enormous diamond pipes in South Africa filled with the densest and heaviest materials—products of crystallization of the interior melts brought out from the deeper layers.

Above this, beginning approximately with a depth of 1,000 kilometres, is the silicate envelope on which we live. We picture it as a rather complicated system of various rocks and minerals though we actually know it to a depth of only 20 kilometres.

Its composition sharply differs from the average composition of the earth and may be expressed in the following figures: one half of it is oxygen; silicon constitutes about 25 per cent, aluminium—7 per cent, iron—4 per cent, calcium—3 per cent, sodium, potassium



Colonnade built of Moscow sandstone Lefortovo (Moscow) and magnesium—2 per cent each; then come hydrogen, titanium, chlorine, fluorine, manganese, sulphur and all the other elements.

We have seen that these figures are the result of thousands of individual calculations and analyses. We get the firm conviction at every step that our earth's hard crust is not uniform, that the distribution of atoms is unusually complicated, and that it is very difficult to form a picture of the structure of the earth's crust composed now of pink, sparkling granite, now of heavy dark basalts, now of altogether white limestones and sandstones or of coloured slates. We know that sulphurous metals, salts, and minerals are dispersed on this variegated and intricate basis in a similarly chaotic disorder. Is it at all possible to find any laws governing the distribution of atoms in this complex picture?

Recent studies of geochemists have shown that this apparent world of accidents has its own unusually clear-cut and inexhorable laws. Geochemists have not only isolated the earth's crust, the silicious scale, from this fiery, live cluster, but have also divided it into separate atoms and are now studying the behaviour of each of them in strict order.

The molten mass and scale resemble the slag which has been drained from the blast-furnace and which has gradually begun to cool. One after another various minerals started crystallizing from it. The first to separate were the heavy substances which began settling to the bottom; the lighter constituents, i.e., gases and volatile substances, rose to the top. Minerals rich in iron and magnesium thus dropped from the molten basalts to the bottom; in them we encounter compounds of chromium and nickel and find the sources of precious diamonds and costly platinum ores; on the other hand, other substances rose to the surface, to the upper field and gave rise to the rocks which we call granites. These proved successive extracts, as it were, of the cooling massif; it is precisely

A hot spring. The water is too hot to touch

these granites that formed the basis of our continents which float, as it were, on the heavy basalt layer that lines the greater part of the ocean floor.

Strict laws of physical chemistry governed this new distribution of atoms in space, and new ideas were born in science at the time geochemists began making use of the laws of physical chemistry.

The process of granite cooling is complex; the granite centres give off superheated steam and volatile gases which permeate through the nearby rocks and form hot water solutions that we know well by our mineral springs. This hot breath surrounds the granite centre with a sort of halo; the gases and vapours with various contents of volatile substances break through the cracks and fractures of the cooling granite rocks; hot underground rivers flow, gradually getting cool and forming on their walls crystalline crusts of minerals; later they change to cold springs on the surface.

In this halo of cooling granite we see primarily the residual melts; these are the famous pegmatite lodes which are, as it were, bearers of the heavy atoms of radioactive ores. They carry with them precious stones, sparkling crystals of beryl and topaz; in them we find traces of tin, tungsten, zirconium and rare metal compounds.

Lodes of quartz with tin and wolframite run in the complex process of gradual stratification; still further are branching quartz lodes with gold and then deposits of zinc, lead and silver which form the polymetallic veins, while far from the hot centre, several kilometres away from the boiling layers of the molten granites, we find compounds of antimony, red crystals of mercury sulphide and fiery yellow or red arsenic compounds.

These ore masses are distributed according to the laws of the same physical chemistry. When they harden in the long fractures of the earth the accumulations of atoms stretch out in long rings or bands regularly following each other around the heated massifs. Grand pictures of these ore zones open up before us on the surface of the earth; some of them run through both American continents beginning in the north somewhere in the region of California. They carry lead, zinc and silver. Others cut across Africa along the meridian. Still others engird in the form of garlands the stable petrified shields of Asia, creating a zone rich in ores and semi-precious stones, traced for many hundreds of kilometres.

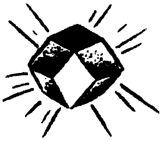
The incomprehensible picture of ore deposits seemingly scattered in disorder is thus transformed for the geochemist into a clear-cut regular picture of distribution of atoms. The greatest practical problems and accomplishments are decided on the basis of this new idea of the natural laws of distribution of atoms in the earth's crust according to their properties and behaviour.

The old observations of medieval miners and the old experience of mining are now replaced by real laws of which Agricola dreamt so much as early as the 16th century when he spoke of the mysterious love of various elements for each other.

M. Lomonosov, the Russian scientist, had the same thing in his mind when he called on the chemists to unite with metallurgists two hundred years ago in order to find the equilibrium and the reasons for the joint discovery of ores and to answer the questions: why zinc and lead were always encountered together, why cobalt so frequently followed silver, why the metals of nickel and cobalt, these two gnomes so hostile to mining, were always found with the strange element uranium.

What is it then that forces the various atoms to be distributed so regularly in granite rocks? Here we have new forces of natural processes; and whereas in the interior of the earth, when the molten cluster was divided into a nucleus, scale and slag, the main laws of division were determined by the nature of the atoms themselves, here new laws have come to take their place.

The atoms and their parts began to combine forming not only a system of piled-up free atoms and molecules, which we call liquid or glass, but also structures which are not found in the interior of the earth and which drift in space only where the cold of interplanetary space cools the stormily moving atoms to below 2,000° C.



This remarkably harmonious structure, which determines the harmony of our world, has been given the name of crystal. We have already mentioned that 1 cubic centimetre of crystal is built up of 40,000 trillion atoms which are located at definite points in space and at definite distances from each other forming sorts of lattices and networks. The entire upper layer of the earth's crust, as well as the overwhelming part of the world that surrounds us, is built of crystals.

The crystal and its laws determine the distribution of elements which may frequently replace each other in these structures; this gives rise to the possibility for some elements to migrate within the crystal, others to form bonds by electric forces of fabulous power, thus creating the strength of the crystal, its mechanical endurance, and its ability to resist all the hostile forces in the universe.

There, in the interior of the cosmic bodies, we find a disorderly chaos of atoms; here, on earth, there is no more chaos, there is an endless series of points and meshes distributed as regularly as the boards of parquet on a floor, or as lamps in a large hall.

We have now come to the earth's surface. The earth's entrails cease to affect the life of the atoms and cede their influence to the sun and the emanations of the cosmos; and under the influence of new types of energy the atom resumes its migrations on the surface of the earth in accordance with the laws of physical chemistry and crystallochemistry.

Half a century ago V. Dokuchayev, Russian naturalist, developed his ideas on the laws of soil formation on the earth's surface in his lectures at Petersburg University. He said that the climate, plants and animals led to the formation of separate soil zones and at the same time the different distribution of atoms of substance in the soil. The soil was revived in his generalizations as a new peculiar world of atoms.

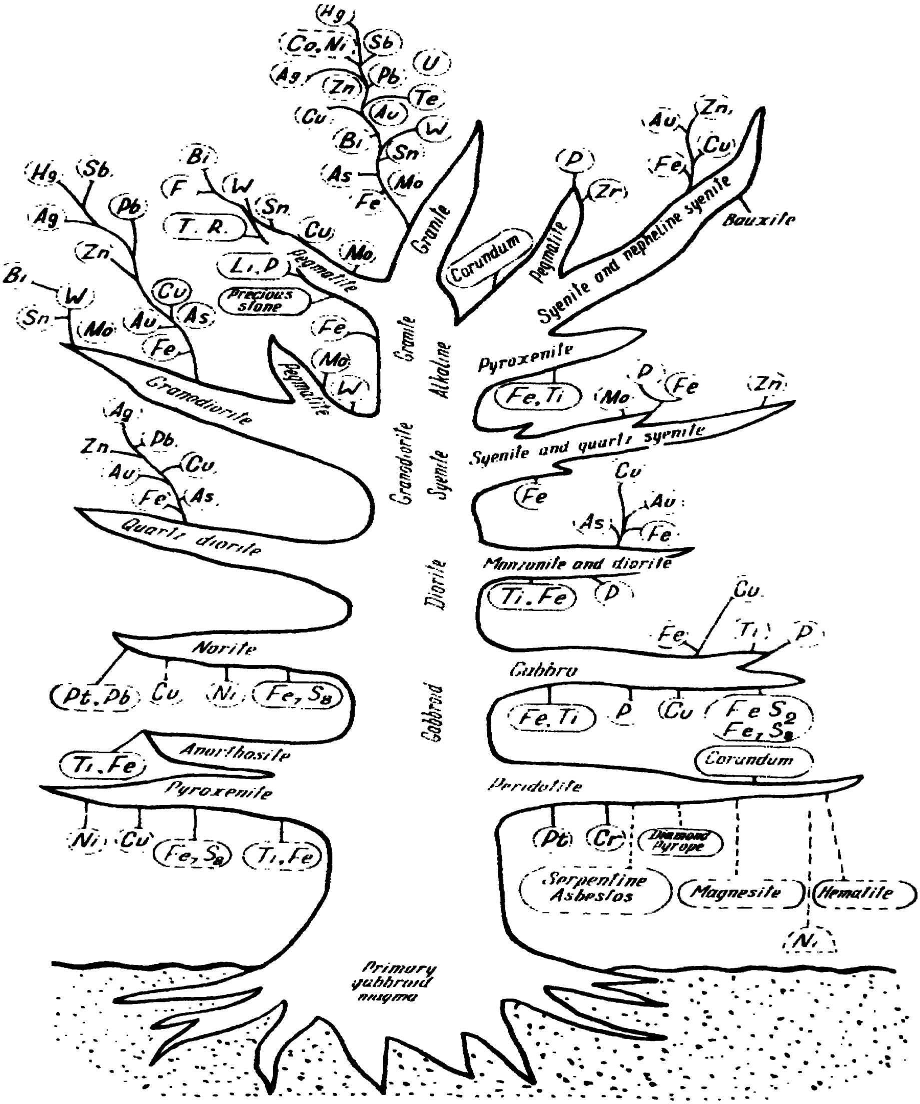
V. Dokuchayev

Dokuchayev was fond of saying: "The soils are the fourth kingdom of nature."

He subordinated to the laws of this world not only the fertility of the soil but the life of man as well. But it is precisely here on this thin film of the earth's surface that the atoms have grown unusually complex. The simple and clear schemes of the quiet growth of crystals in the interior have proved insufficient here.

The complex geographical landscape has subordinated the atoms themselves, while the frequent changes of climate, seasons, day and night and the life's processes began to leave their imprints and to demand new forms of equilibrium and new conditions of stability.

In the interior of the earth it is quiet; there is a quiet process of spatial distribution of crystals, while on the surface there is a stormy kingdom of variable, contradictory influences, a struggle of forces, a change of temperatures and a domination of processes of destruction. Here, instead of our precise crystalline structures, their fragments,



Geochemical diagram of the distribution of elements and some minerals in connection with the distribution of rocks from the primary magma

Extinct two peaked volcano in California. Height 4.300 metres

as a new dynamic system, acquire the greatest importance. These fragments we call colloids.

There arises a contradiction between the world of order in the interior of the earth and the chaotic world of jelly-like colloids on the surface. Under the rapidly changing conditions of surrounding nature the chemical reactions cannot proceed so quietly and regularly as in the interior. The construction of the crystal just begun breaks up and is replaced by a new one. The fragments of crystals sometimes merge, and these large particles, sometimes built of hundreds and thousands of atoms, give rise to a new form of substance, to an unstable system of colloid, i.e., the jelly and glue which we know so well in the organic world.

But it is not only this force of destruction which characterizes the system of minerals of the earth's surface; it conceals tremendous active forces; it contains more energy than the dead, stable system of crystals.

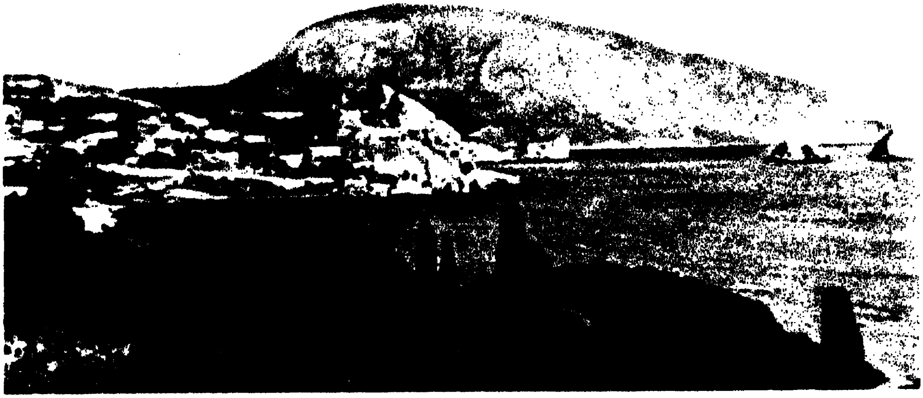
In the clays, and in various types of brown-iron and manganese films that surround us, in the multiformity of the different atomic combinations of iron, aluminium and manganese, in the balls and concretions of phosphoric compounds new forces come into play caused by the contact of various media with each other; these new forces of chaos manifest themselves wherever there is construction side by side with destruction, where new regularities arise and determine the nature of the soils, facilitating migrations of individual metals and causing their mutual exchange in the soil.

We thus gradually approach the last stage in the history of the atom—the processes of life. The colloid has already paved the way for the creation of the new system; this complex concatenation of purposive molecules, which conceal tremendous surface forces, gives rise to embryos of a new substance which is the living cell.

It is here, in this peculiar and flexible structure, where the atoms are now bound and now free, that life was born as a natural development, as a logical consummation of the system of atoms that was becoming ever more complicated. Following the complex paths of evolution this life only reproduced the pictures we have painted above. Subject to a new form of grouping it began to complicate the atomic structure and has become the dominating phenomenon on the earth's surface from the minutest unicellular organism all the way up to man.

We cannot erase anything from our surroundings. Life together with inorganic nature, air and water has merged into a single whole and has created the numerous geographic landscapes that surround us. This is the highest form of the system of atoms which has come about as a result of the laws of evolution and development of the organism. The Homo sapiens has come into being with an intellect capable of cognizing the mighty laws of energy which govern this new, still more unstable and at the same time still more powerful active system.

Cliff of volcanic tuff. Karadag, the Crimea



The Crimea. Gurzuf. General view against the background of the Medved Mountain of laccolith or "would-be volcano"

The history of migrations of the atom shows us how its fate has gradually grown more complicated.

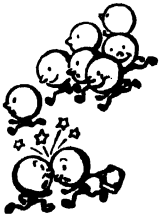
It began as an electrically charged free proton; subsequently nuclei were formed. It grew more and more complicated, and with the transition to the colder system of the ~~cosmos~~ the electron shell came back to the atom. These atoms have gradually merged in a regular and rigid geometric form, in what we have named a chemical compound.

The crystal was the form of expression of these laws, the form of the greatest order, the greatest harmony, the least reserves of energy and, therefore, the most inert form of substance devoid of any free force. But right there and then complication began and a new colloidal system of atoms and molecules came into being.

The living cell was created; complex molecules began to be built of hundreds and thousands of separate atoms; and as the highest form of the still undeciphered chemical system protein bodies came into being and created the multiformity, complexity and mysteriousness of the organic world that surrounds us.

But in the history of nature the atom has always rushed about in quest of new forms. We cannot say as yet whether there are any new

Studying the eruption of a Kamchatka volcano



forms of equilibrium more stable than crystals and more actively charged with energy than living substance. All our ideas about nature run up against the insufficiency of our knowledge of the new paths travelled by the atom, and nobody would dare say that we have already learned about the entire course of its migrations and that man has already mastered the powerful forces which he could unleash in the atomic cluster.

ATOMS IN THE AIR

What is air? How little we know about it and what little interest we even show in this question. We have grown used to the fact that we are surrounded by air and, like health, we begin to appreciate it only when we lose it, when we get into circumstances where there is not enough air.

We know how difficult it is to breathe at high altitudes, how some people grow weak because of the mountain sickness already at an altitude of three kilometres; we know how fliers suffer when they rise in their planes to an altitude of more than five kilometres; at an altitude of from eight to ten kilometres there is definitely not enough air and the supply of oxygen on the plane must be made use of.

We know how hard it is to descend into mines, how long it rings in your ears before you get used to the new air pressure at a depth of 1,500 metres.

The air now constitutes one of the most interesting problems not only for science, but also for the chemical industry.

It was a very, very long time before man could understand what air actually was. For a number of centuries the conviction reigned in primitive chemistry that air was composed of a special gas—phlogiston—and that when anything burned it liberated phlogiston which filled the world as a special fine substance.

Lavoisier

Then, the brilliant discovery of Lavoisier made it clear that the air was essentially composed of two substances: one life-giving substance, which was named oxygen, and another, indifferent to life, which was, therefore, given the name of "azote" (the Greek for "lifeless"). The latter is now more commonly known as "nitrogen" in English.

In 1894 it was quite unexpectedly discovered that the composition of the air was much more complex and that in addition to nitrogen, the air contained a number of other, heavier chemical elements, which play an important part in it.

Modern physicists set the composition of the air as follows:

	By weight		By weight
Nitrogen	75.7%	Neon	0.00125%
Oxygen	23.01%	Helium	0.00007%
Argon	1.28%	Krypton	0.0003%
Carbon dioxide	0.03%	Xenon	0.00004%
Hydrogen	0.03%	Water vapours - variable amounts	

Today we know the composition of the air ocean so well that not a single drop dispersed anywhere in it escapes the attention of our chemists.

Now it turns out that the gaseous ocean that surrounds us is not only the basis of all of our life, but also that of a new great industry.

The British have recently estimated that the entire population of England and Scotland daily consumes up to 20 million cubic metres of oxygen from the air, while special installations extract up to one million cubic metres of this gas for the needs of industry during the same period of time.

At the same time industry burns coal and oil, thus consuming oxygen and giving off large amounts of carbon dioxide to the atmosphere. The same process goes on in living systems. For example, man gives off about three litres of carbon dioxide per day.

To give the reader a good idea of what this figure means suffice it to point out that it takes a eucalyptus, a large tree, one day to decompose approximately one-third of the carbon dioxide exhaled by

Eucalyptus alley on a state farm in the central part of the Kolchis Lowland (Georgian S.S.R.)

one person and return free oxygen to the atmosphere. It follows that three large eucalyptus trees will decompose as much carbon dioxide as is given off by one person and will thus restore the balance in the composition of the atmosphere.

This shows the great importance of the vegetation that surrounds us and that we so carefully safeguard and plant in our cities. The life of plants is the only source of restoring the oxygen consumed by man. Meanwhile, oxygen is being used in ever larger amounts.

In 1885 small factories producing barium peroxide laid the basis for the industrial utilization of the oxygen contained in the air. Today the oxygen of the air serves as the basis of several branches of the chemical industry. Pure oxygen instead of air is now blown into blast-furnaces. Oxygen is an indispensable oxidizing agent in a number of branches of the chemical industry.

The number of installations which extract oxygen from our atmosphere through liquid air grows with each passing year.

In addition to oxygen, man has been making increasingly wider use of other gases.

Until very recently industry made no use of argon which constitutes one per cent of the air. Now complex installations annually extract almost one million cubic metres of this rarest of gases from the air.

Not many of us know that more than 1,000 million electric bulbs are annually filled with this gas.

The luminous advertisements of large cities annually make ever greater use of neon, another noble gas contained in the air. There is very little of it in the air ocean—one part of neon per 55,000 parts of air. And still the neon industry has been growing from year to year.

Helium is also beginning to be extracted from the air. There is still less helium than neon, though the atmosphere above each square kilometre of land contains about 20 tons of this most valuable gas of the sun. Helium is extracted from the air and mainly from underground gaseous streams; it is used for filling dirigibles; in refrigeration engineering it is employed for producing the world's lowest temperatures.

Even the rarest gases, krypton and xenon, are beginning to be used in our industry.

Beacon of neon tubes at an airfield

The air contains less than 0.001 per cent krypton. And yet how helpful it would be if we could get it in greater amounts because we could then increase the brightness of electric bulbs by 10 per cent, and with the use of xenon by 20 per cent. This means our lighting installations would consume 20 per cent electric power.

But the most important raw material for industry extracted from the air is of course nitrogen.

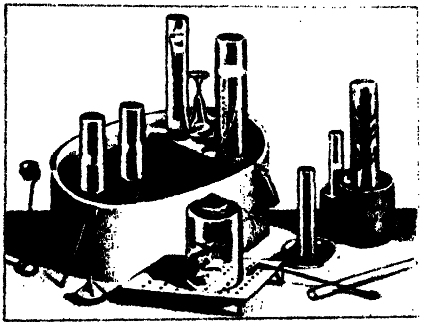
The first attempts to utilize nitrogen compounds for fertilizer were made in 1830.

No one thought of the nitrogen contained in the air at that time and even the saltpetre brought by ships from Chile did not always find application in the poor fields of Western Europe. However, the gradual introduction of chemistry into agriculture required ever greater amounts of the life-giving substances on which the chemical life of plants is built, i.e., nitrogen, phosphorus and potassium. The need for nitrogen began to increase to such an extent that in 1898 Crookes, physicist and chemist, predicted a nitrogen famine and suggested that new methods for the extraction of nitrogen from the air be found.

Time wore on. Chemists have learnt to transform the nitrogen of the air into ammonia, nitric acid and cyanamide by means of electric discharges.

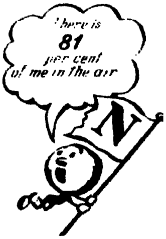
During the First World War nitrogen, which was necessary for the production of explosives, became the object of numerous investigations. More than 150 nitrogen works are now operating throughout the world; they extract four million tons of nitrogen from the air annually. But even this figure is negligible compared with the vast reserves of this gas which constitutes approximately 81 per cent of the total volume of the air.

Suffice it to say that all of the nitrogen installations in the world annually extract as much nitrogen as is contained in a column of the atmosphere over 0.5 square kilometre of the earth's surface. We picture to ourselves the new industrial ways of utilizing the air as follows. Industry is making increasing use of the constituents of the aerial ocean. The atmosphere is transformed into an immense source of mineral raw materials, the reserves of which are practically inexhaustible. However, man has not yet found the means of mastering these reserves.



Instruments with which Priestley studied the composition of the air in 1774-90

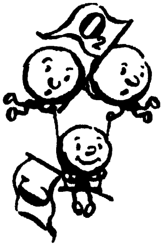
The processes by means of which man divides the air into its constituents are quite imperfect. The extraction of nitrogen requires high pressures and tremendous quantities of energy. To separate the noble gases and obtain oxygen requires complex and expensive machinery; the air must first be transformed into the liquid state in order that the various gases may then be extracted. Great headway has been made in this direction in the Soviet Union in recent years.


There is 81 per cent of me in the air
N

New remarkable machines, which make it possible very thoroughly to divide enormous quantities of air into its constituents, have been built at the Institute of Physical Problems of the U.S.S.R. Academy of Sciences.

But we can already imagine little machines installed in every room. We open a tap marked "oxygen," and instead of air a bluish liquid cooled to minus 200° C. comes flowing out of it.

We open another tap and a liquid noble gas, krypton or xenon, flows out of it drop by drop, and somewhere on the bottom, like ash in a stove, solid carbon dioxide accumulates; this compound is fed to a special press and gives us hard dry ice which you have all seen when buying ice-cream; this dry ice cools our apartments on hot days



In the picture I have just painted I may have run a bit too far ahead. There are no such portable little machines which can be plugged in in our rooms as yet, but I am sure it will not be long before we are able to utilize the riches contained in the air for our needs and the chemical industry is built on the immeasurable reserves of nitrogen and oxygen, the two elements of outstanding importance to the life of the earth.

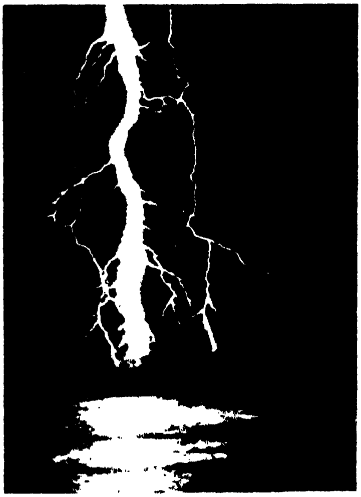
I could finish my story right here, but I do not believe it would be comlpete.

I have not said anything about utilizing the carbon dioxide of the air or about the possibilities of making use of all the gases formed during the combustion of coal and wood and the kilning of limestones.

Industry is already calculating the enormous amounts of carbon dioxide which are thrown out into the air as waste-products. It proposes that the carbon dioxide be used for manufacturing dry ice and it wants to extract from our atmosphere the 0.03 per cent carbon dioxide it contains.

The physicists go even farther; they say that our air consists not only of the ten gases mentioned above, but that it contains tremendous quantities of even rarer gases which are dispersed in millionths of one per cent, i.e., radioactive gases.

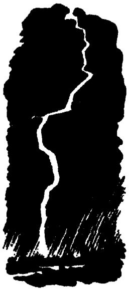
They mean the emanations of radium and of different volatile gases, the products of disintegration of light metals. These gases do not live long in our atmosphere: some of them live for days, others for seconds, and still others for millionths of a second. The air is saturated with these products of disintegration of world atomic nuclei. The cosmic rays destroy atoms and give rise to unstable gases at each step; these gases must disappear again and change to stabler forms of solid substance.



Photograph of a lightning

Chemical reactions are continuously taking place in the aerial ocean. Most intricate processes occur between the dispersed atoms of substance and we still know very little about the constant and complicated shifts and about the electric discharges which occur in this aerial ocean around us.

To solve this problem is to make one more step towards subordinating nature to our needs.



ATOMS IN WATER

The springs, rivers, seas, oceans and underground waters together form the continuous water shell of the earth, the so-called hydrosphere. The sun constantly evaporates water from the vast surfaces of the oceans.

In the atmosphere the water condenses and falls on the earth in the form of rain, snow and hail. It erodes the soils, lixiviates them, breaks up rocks, dissolves a mass of various substances and carries them all back into the seas and oceans.

Water, thus, runs its cycle many millions of times: ocean -atmosphere -earth -ocean. And each time it extracts new amounts of water-soluble substances from the solid rocks of the earth.

It has been estimated that all the rivers of the world annually carry from the surface of the earth about 3,000 million tons of substances dissolved by them into the ocean. In other words, every 25 thousand years the waters destroy and carry away from the earth a layer of rock nearly one metre thick.

The water really does a lot of work on the earth.

Water, whose formula is H_2O, is one of the most abundant substances on earth.

The volume of water contained in the world ocean constitutes 1,370 million cubic kilometres!

Water has played an enormously important part in the history of the earth and, consequently, in geochemistry.

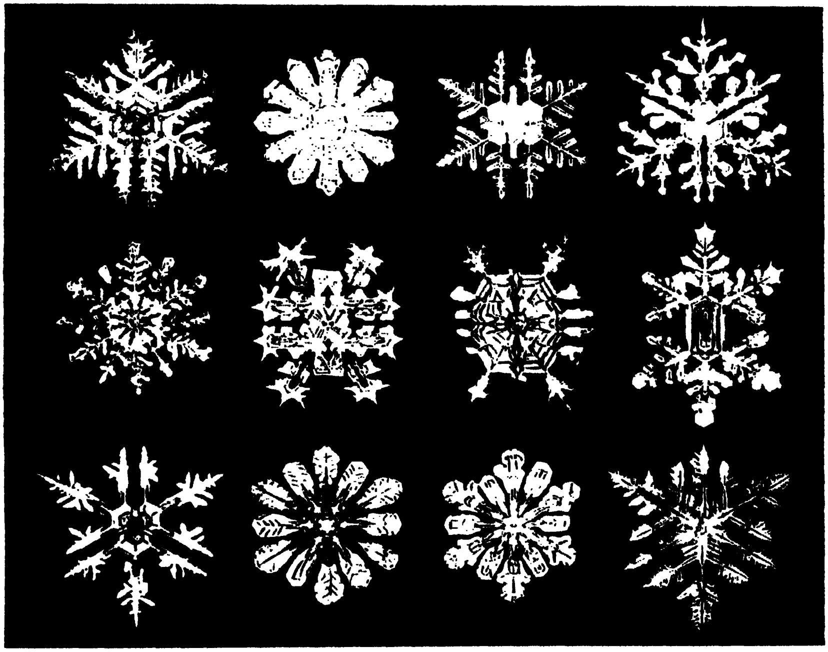
This is why the geological sciences once had a hypothesis that all rocks on earth had originated in an aqueous medium.

The adherents of this hypothesis, the Neptunists, named after Neptune, the mythological god of water, contested the Plutonists, who in their turn maintained that all rocks on the earth arose from molten masses which had poured to the surface from the interior of the underground kingdom of the god Pluto.

Today we know that both these forces, water and volcanoes, were involved in the formation of the earth's rocks.

There is hardly any water in nature that does not contain certain admixtures or substances dissolved in it. In other words, nature has no distilled water. Even rain water contains carbon dioxide, traces of nitric acid, iodine, chlorine and other compounds.

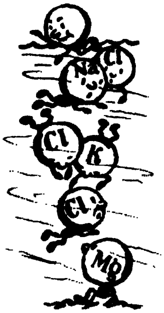
It is very hard, not to say impossible, to obtain chemically pure water. The gases of the air and the walls of the vessel containing the water dissolve in it, even though in very small quantities. For example



Shapes of snow flakes

Fantastic shapes of eroded sedimentary rocks. New Zealand

thousand millionths of a fraction of silver are dissolved in the water contained in the silver vessel. The silver of a tea-spoon dissolves in water in negligible amounts. A chemist can hardly notice these traces. But certain lower organisms, for example seaweeds, are so sensitive to traces of silver and to some other atoms in the water that they are killed by them.



Natural water, while running through extraordinary diverse terrestrial rocks — sands, clays, limestones, granites, etc., certainly, extracts various compounds from them. Some scientists say that if we knew the bed of the river we could tell the composition of its water.

But despite the fact that alumosilicates, as we already know, are abundant in nature, the waters do not, as a rule, contain large amounts of aluminium or silicon. If these metals are present, they are there mainly in the form of lees or in mechanical suspension. On the other hand, all the waters of rivers and seas always contain alkalis — sodium, potassium, as well as magnesium, calcium and other elements. But what does all this mean?

It appears that the chemical composition of the salts dissolved in waters depends to a great extent on the degree of their solubility in water. The most soluble compounds are the most usual constituents of natural waters. As before stated, the main mass of the salt residue of natural water always consists of atoms of sodium, potassium, calcium, magnesium, chlorine, bromine and some other elements.

The salt-saturated waters, i.e., brines, also contain precisely these soluble compounds of atoms eroded from rocks.

Niagara Falls in America

The ocean is thus a storehouse of soluble salts which have accumulated in it since the existence of the earth as a result of the continuous circulation of water between the continent and the ocean.

Scientists attempted to estimate the amount of salts annually carried by rivers into the oceans by the amounts of the salts dissolved in the ocean. On this basis they estimated the age of the ocean or the number of years required for the water of the ocean to acquire the concentration of salts now observed. However, the figures obtained are not exact.

On the coast of the Azov Sea

Thus the soluble compounds of atoms form the basis of the salt constituent of natural waters. The water of the ocean contains 3.5 per cent salts, of which more than 80 per cent is sodium chloride, the well-known common salt. Everybody knows that it dissolves very easily.

Geyser in Yellowstone Park (U.S.A.)

The other soluble compounds are found in the water in only very small quantities. All chemical elements can be found in any natural water, i.e., seas and underground springs. It depends on how good our methods of research are.

If we remember there are altogether about 100 chemical elements, we shall easily understand how the waters encountered in nature differ in their composition. As a matter of fact, scientists have established the existence of numerous classes of water.

The waters of the ocean anywhere on the surface and in the deep (but away from the coast) are very constant in composition and of all chemical elements. River-waters are very similar in composition but less constant. The fact that the rivers flow in different rocks and under different climatic conditions leaves an imprint on their composition. Thus the rivers of the northern latitudes contain more iron and humus and are often even coloured by them. The rivers of the middle latitudes contain mainly sodium, potassium, sulphates and chlorine. In the warmer latitudes, especially in regions where the water does not drain into seas or oceans, river-water, and more frequently, lake-water, is salty.

A similar variation in the composition of water according to zones is observed also vertically for the ground waters. The deeper these waters run, the more they resemble brines. The waters whose composition differs most are precisely the mineral underground waters which not infrequently form mineral springs, often medicinal, as they come to the surface.

Here we can find waters containing calcium, iodine, bromine, radium, lithium, iron, sulphur, magnesium, boron, etc.

The origin of these mineral waters is connected with the solution of the mineral deposits by underground waters, with the process of lixiviating rocks of different composition.

To divine the entire process by which these waters are formed by their chemical composition is an entertaining and, at the same time, a very important scientific problem.

The following table shows the composition of sea-water (in percentages):

Oxygen	86.82	Aluminium	0.0000011
Hydrogen	10.72	Lead	0.0000005
Chlorine	1.89	Manganese	0.0000004
Sodium	1.056	Selenium	0.0000004
Magnesium	0.14	Nickel	0.0000003
Sulphur	0.088	Tin	0.0000003
Calcium	0.04	Cesium	0.0000002
Potassium	0.04	Uranium	0.0000002
Bromine	0.006	Cobalt	0.0000001
Carbon	0.002	Molybdenum	0.0000001
Strontium	0.001	Titanium	0.0000001
Boron	0.0004	Germanium	0.0000001
Fluorine	0.0001	Vanadium	0.00000005
Silicon	0.00005	Gallium	0.00000005
Rubidium	0.00002	Thorium	0.00000004
Lithium	0.000015	Cerium	0.00000003
Nitrogen	0.00001	Yttrium	0.00000003
Iodine	0.000005	Lanthanum	0.00000003
Phosphorus	0.000005	Bismuth	0.00000002
Zinc	0.000005	Scandium	0.000000004
Barium	0.000005	Mercury	0.000000003
Iron	0.000005	Silver	0.000000004
Copper	0.000002	Gold	0.0000000004
Arsenic	0.0000015	Radium	0.00000000000001

It will be seen from the table that sea-water contains 99.99 per cent by weight of the first fifteen chemical elements while the remaining 74 elements constitute about 0.01 per cent.

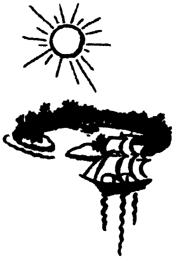
In absolute figures, however, this is not so little, because there are, for instance, millions of tons of gold in sea-water.

Scientists have made many attempts to build a physico-chemical factory which would make the extraction of gold from sea-water profitable. So far all their attempts have failed.

A concentration of bromine, iodine and, of course, chlorine, i.e., the chemical elements which are very important to man, is characteristic of sea-water. The iodine contained in sea-water is consumed by the seaweeds and the marine animals. It is from seaweeds that man extracts the main mass of industrial iodine.

On the beach in Sukhumi — Abkhazian A.S.S.R.

When the seaweeds die, the iodine they contain goes over to the silt on the bottom of the sea. Rocks are gradually formed from the sea-silt. The waters are squeezed out of them and ground waters are formed. These ground waters take the iodine with them. Ground waters are often discovered in drilling for oil. They are rich in iodine and bromine. Man has now learned to extract these elements from them. Sea-water is an unlimited reservoir of bromine which is now extracted in a number of places directly from sea-water (like magnesium).



The history of calcium atoms in natural waters is of particular interest because they are frequently supersaturated with ions of calcium and in these cases the latter precipitates as calcium carbonate and forms limestones or chalk.

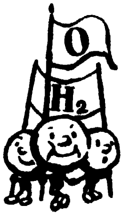
Carbon dioxide plays a big part in the history of calcium. A surplus of carbon dioxide makes calcium dissolve while its insufficiency makes calcium carbonate precipitate from solutions. And if we recall that green plants consume carbon dioxide, we shall get a clear picture of their role in the precipitation of calcium from water. As a matter of fact, enormous islands in the warm sea — atolls — are fully formed

The Sprudel Mineral Spring in Karlovy Vary (Carlsbad) Czechoslovakia. The temperature of the water is close to 75° C.; the spring spurts to a height of 9 metres

of calcium carbonate deposited as a result of the vital activity of marine plants as well as from the lime skeletons of marine animals.

We wanted to show by this example that the composition of natural waters is considerably influenced by the living population of the reservoir.

Without the knowledge of how "living substance" influences the composition of water, it is impossible fully to understand how the waters of the rivers, lakes, seas and oceans have come to have their present-day composition



ATOMS ON THE SURFACE OF THE EARTH. FROM THE ARCTIC TO THE SUBTROPICS

I remember taking a trip from Moscow to the South of Greece when I was still a boy; my childish mind has for ever retained the picture of changing colours which unfolded itself before me as I moved southward.

It was a clear day in Moscow but I saw the grey monotonous earth, grey-red, brown clays of the Russian serozem. This was followed by a more motley picture of chernozem colours in the environs of Odessa, illumined by the bright rays of the spring southern sun. I remember how these colours changed as we entered the Bosphorus: the blue of the water and the chestnut-brown soils of the vineyards. I can still see the landscape of southern Greece before me the dark-green cypress trees, the red soils and the red films of iron oxides amid the snow-white limestones.

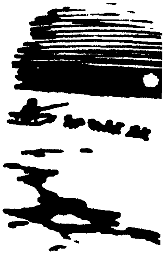
I remember the deep impression this picture of changing colours had made on me and how I insisted that my father explain why the colours changed as they did. It was only many years later that I understood I had witnessed one of the greatest laws of the earth's surface, the law of the oxidative chemical processes which vary so much at the different latitudes of the earth.

Since then I have chanced to travel a great deal through the Soviet Union, from the continuous forests of the taiga, through the plains, tundras and polar oceans all the way to the snow-capped summits of the "roof of the world" the Pamirs. And this picture of the various chemical reactions and the different fates of the atoms on the surface of the earth from the deepest Arctic to the hot subtropics rose before me each time but on an ever larger scale.

Edge of glacier in Alaska

Let us take a look at this small map and then travel along the arrow drawn on it from Spitsbergen in the North to Ceylon in the Indian Ocean.

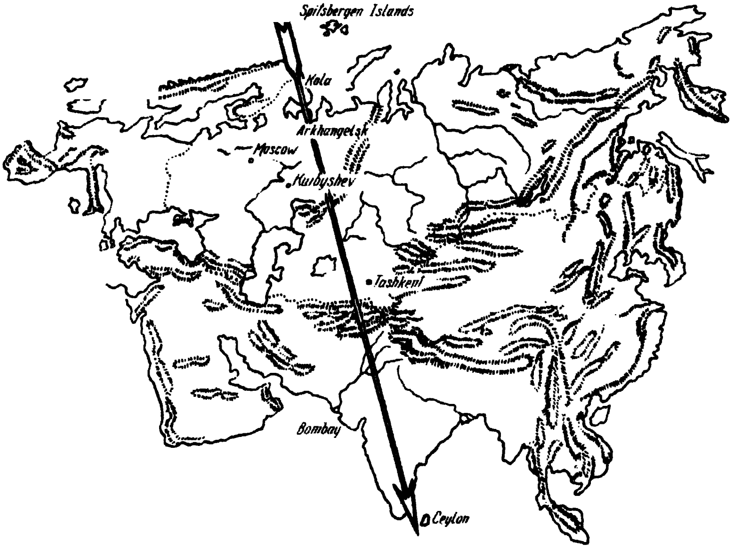
Around old Svaldbard we find continuous ice; it is a dead ice desert. There are no chemical reactions; rocks do not break up into clays or sands; the action of frosts spreads inward and tremendous boulder-stones are formed. Only now and then, at the seashore colonies of birds, do remains of organic life accumulate and films of phosphates are nearly the only minerals amid the continuous ice.



The chemical reactions occur just as slowly on Kola Peninsula or in the Urals transpolar region. How fresh all the rocks on Kola Peninsula are! On a cold morning you can observe the rocks through binoculars dozens of kilometres away as if you were viewing them in a museum. Thin films of brown iron oxides can be seen over vast spaces. Only in lowlands do peat bogs accumulate, the organic substance of plants burns slowly and is transformed into brown humic acids; the spring waters carry them away together with other soluble salts colouring the layers of jelly-like masses of the peat bogs and sapropels in lakes and marshes.

We can observe other chemical reactions farther south, in the vicinity of Moscow. Here, too, the combustion of organic matter is slow, the same stormy spring waters dissolve iron and aluminium, white and grey sands surround the environs of Moscow and bright spots of blue layers of phosphates gleam here and there in the vast peat bogs.

Further south the colours gradually change, the course of chemical reactions alters, and the atoms find themselves in new conditions. The chernozems of the Middle Volga regions replace the grey argillaceous soils of Moscow. We see how the bright sun gradually modifies the surface of the earth, provoking ever stormier, ever more vigorous chemical processes.



As soon as we cross the Volga we encounter new natural reactions: we find ourselves in a vast salt zone which stretches from the borders of Rumania through Moldavia, along the slopes of the Northern Caucasus, runs through all of Central Asia, and ends on the Pacific Coast. Various salts of chlorine, bromine and iodine accumulate. Calcium, sodium and potassium are the metals of these salts in the firths and dying lakes, scores of thousands of which are scattered over the territory of this zone. Here we observe a complex process of sediment formation.

Still further south we find ourselves in the region of deserts. A new picture rises before our eyes: enormous salines with their white fields gleam amid the green spots of the steppe vegetation across which the Amu-Darya carries its chocolate-red waters. Bright colours denote new chemical reactions, the atoms shift, and in the sands acquire a new chemical equilibrium. Some of them accumulate as sands which form deserts, others are dissolved, are transported by winds and stormy tropical rains, and precipitate in the salines and sors amid the deserts.

An Arctic landscape. A geologist with a dog team on Severnaya Zemlya

In the foothills of Tien Shan we see still brighter colours. Here stormy chemical reactions are encountered at every step, and the migration paths of the atom on the surface of the earth are very complex. I am still impressed by those bright and variegated colours which struck my eye when I visited one of the remarkable deposits for the first time. In my book on the colours of stones I described this picture as follows:

"Bright blue and green films of copper compounds covered fragments of rocks now deepening into olive-green, velvety crusts of vanadium minerals and now interlacing in azure and blue tones of hydrous silicates of copper.

"Numerous compounds of iron its oxide hydrates – lay before us in a motley scale of shades. There were yellow, golden ochres, bright-red hydrates with low water content, brown-black combinations of

Glacier in Arctic regions

Desert landscape. Sand dunes in the Kara Kums (Turkmen S.S.R.)

iron and manganese; even rock crystal acquires bright-red colours, transparent barite becomes yellow, brown and red 'ore barite': red needles of alaite free vanadic acid are crystallized on the pink clayey sediments of caves, while bright green-red sheets of the newly-formed mineral grow on the white bones of the human skeleton."

The picture of the variegated bright colours is unforgettable, and the geochemist scrutinizes it in order to guess its cause. He sees, first of all, that all the compounds are highly oxidized and that these minerals are characterized by the highest degree of oxidation of manganese, iron, vanadium and copper. He knows that they owe this to the southern sun, the ionized air with its oxygen and ozone, the discharges of electricity during tropical thunderstorms, when nitrogen is transformed into nitric acid.

But the arrow leads us farther beyond the border of the sands. Climbing to an altitude of 4,000 metres we find ourselves in a desert again, but this time, in a desert of ice; here we see neither the bright colours nor the migration of atoms we have just observed in the lowlands of Central Asia. Before us is nearly the same picture we saw on Novaya Zemlya and Spitsbergen. All around there are immense boulderstones of mechanical sediments; the fresh rocks hardly know any chemical reactions, and only here and there amid the snows and ice we see afflorescences of solitary salts and accumulations of saltpetre.

This picture resembles the arctic wastes, and only rare thunderstorms remind us of life; they form electrical discharges in the air and create particles of nitric acid which precipitates in the form of saltpetre in the alpine deserts of the Pamirs and, in still greater quantities, in Atacama Desert in Chile.

In Central Tien Shan (Kirgiz S.S.R.)

But let our arrow lead us further across the heights of the Himalayas, and we shall again see the bright colours of the southern subtropics. Continuous warm rains are followed by a dry tropical summer, and most complex chemical reactions occur on the surface of the earth, transporting soluble salts and accumulating enormous layers of red sediments, ores of aluminium, manganese and iron.

Further on, we run into the blood-red laterite soils of Bengal. Wild wind-spouts sometimes drive these soils skyward.

We now come to the chocolate-red colours of the soils of tropical India; we see gleaming fragments of rocks heated by the sun and covered by a sort of semi-metallic lacquer; only here and there do we observe deposits of "baths" of white and pink salt interspersing this picture of the red soils of the Indian subtropics.

In the south of India, where the emerald-green waters of the Indian Ocean wash the red shores and the depths of the sea bring the breath of the volcanic eruptions of basalt, we observe an even livelier and wider picture of migrations of the atoms.

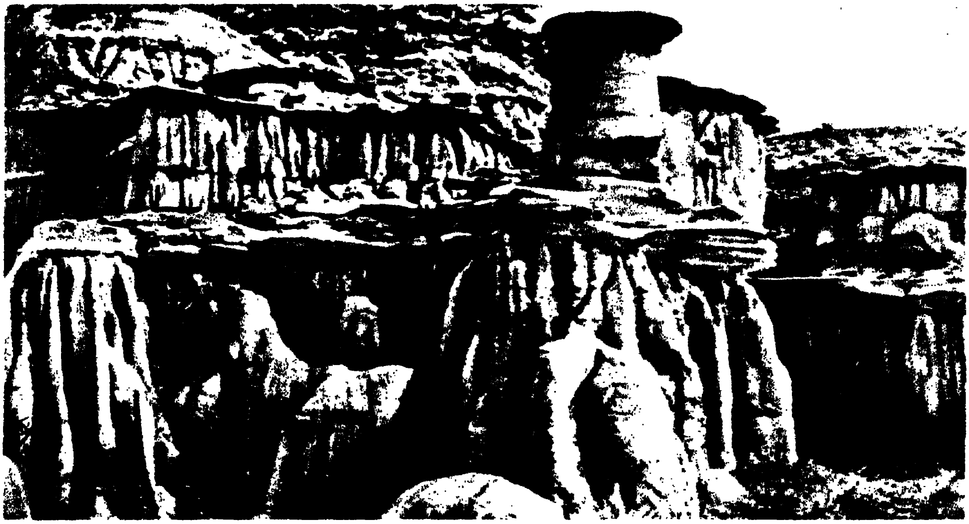
Complex chemical formations vary the picture of the sea-bottom at each step, beginning with the shallow waters near the coast with their shells, sea-mosses and corals, and ending with the deep waters with their coral reefs and immense accumulations of coral limestones.

Subtropical landscape. Palm alley in the city of Gagra on the Caucasian coast

In the deep waters, in silt, where the remains of skeletons of organisms accumulate, phosphoric salts are formed in the shape of phosphorite nodules.

Radiolarians with their armour of silica brought by rivers construct their open-work shells, while Foraminifera consume barium and calcium in building their skeletons. Such is the speed with which the atoms replace each other from the Arctic to the subtropics, and so great are the processes of migrations of the individual elements on the surface of the earth.

What causes this difference in the landscapes between the extreme north and the tropical south? Today we know it is the action of the solar rays, fading, an abundance of moisture, and the high temperatures of the earth. It is also caused by stormily developing organic life, which



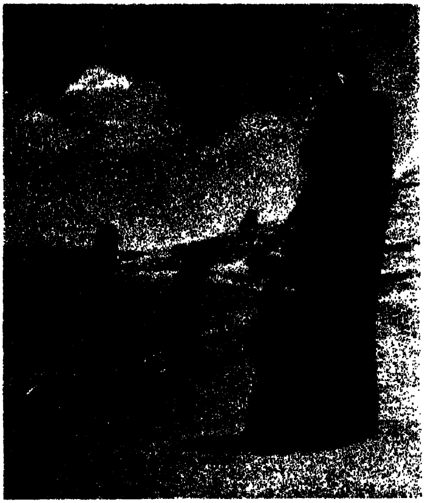
Weathering of clay layers

requires tremendous amounts of various atoms. Large accumulations of the remains of living cells decompose in the hot southern sun into carbon dioxide, and the carbon dioxide saturates the water with its acid solutions.

The chemical reactions are many times as fast in the south; we geochemists very well know one of the principal rules of chemistry that in most cases the rate of the usual chemical reactions increases two-fold for every ten degrees rise in temperature.

And we begin to understand the immobility and rest of the atoms in the arctic wastes and the intricate paths of their migrations in the subtropics and the deserts of the south. We see that we can now talk about *chemical geography*, that nature with its diversity of continents and countries is linked by strong ties to the chemical processes which take place all around.

Among the factors determining the course of geochemical processes, man himself acquires ever greater importance. In the last hundred years his vigorous activity has been connected with the middle latitudes and he is only gradually beginning to master the wastes of the Arctic and the sand deserts of the south. He brings along his own complex



Mysterious statues hewn from volcanic rock; Easter Island in the Pacific

chemical reactions and disturbs the natural processes, provoking new movements and migrations of the atoms he needs. The new chemical geography was outlined a long time ago when the principles of the soil science were laid down; this science was born in Russia and its future is bound up with the fate of the fertility of the fields.

And we recall how in the eighties of last century in a small lecture hall at Petersburg University V. Dokuchayev, the famous "father of soil studies," painted in his lectures fascinating pictures of a new science by pointing out the soil zones which cover the earth from the polar tundras to the southern desert.

At that time his wonderful construction could not yet be translated into the language of chemistry. But now, when chemistry has powerfully invaded the field of geological science, when agrochemists have begun to control the life of plants and the reactions which occur in the soil, when the investigations of geochemists embrace all spheres of atomic migrations, we begin to understand the intricate path travelled by each atom in the different latitudes of our earth.

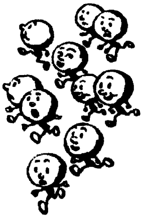
At the same time, the past teaches us that these latitudes changed. The life of our earth's crust has varied over a period of nearly 2,000 million years, the location of the poles altered, mountain ranges at first raised their snow-capped summits only in the polar countries, but folding gradually shifted southward, forming such ranges as the Alps and the Himalayas. Large seas engirdling the earth also shifted from north to south; zones changed and with them changed the landscapes. In each place the seas were repeatedly replaced by mountains, the mountains by deserts and by seas again.

The course of the chemical reactions and migrations of individual atoms, thus, changed in the long geological history of the earth, and the soils and superficial layers at each given point of the earth are only a reflection of the chemical fates suffered by the atoms in the long periods of the diverse history of the earth.

Today we know that everything lives, that everything is fluid, that everything changes in time and space, and that the most mobile thing in nature in constant quest of new paths is the atom, the primordial brick of which the remarkable structures of the world are made, the atom which eternally seeks rest and equilibrium and obeys the principal laws of the natural processes.

Figure of Buddha 52 metres high hewn from sandstone. Afghanistan

It seeks rest, but does not and never will find it, because in nature there is no rest, there is only eternal matter in eternal motion. . . .



ATOMS IN THE LIVING CELL

We can see with the naked eye that coal is formed from remains of plants. The shells of the fossils of marine molluscs not infrequently form layers of limestones.

But if we examine limestones, chalk, diatomite and many other so-called sedimentary rocks under the microscope, we shall see that they consist completely of the remains of skeletons of microscopic organisms.

In a word, geology has long since recognized the enormous part played by the organisms inhabiting the earth in all the processes which occur in the earth's surface.

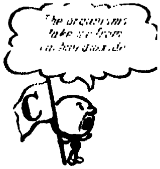
Living substance takes a more or less active part in such geochemical processes as the formation of rocks, concentration and dispersion of separate chemical elements, precipitation of substances from water, and formation of limestones from lime skeletons of organisms.

But by far not all marine organisms have lime skeletons. Some of them, for example sponges, have silicious skeletons.

Even more essential, however, is the fact that in the process of life all organisms of the earth, plants and animals, extract, consume or devour and again liberate enormous masses of various substances and pass these substances, as it were, through themselves.

This process is especially rapid in the minutest organisms: bacteria, simplest seaweeds, and other lower organisms. It is connected with the enormous rate of their reproduction. They divide every five to ten minutes but do not live long.

Estimates show that this process of cell division involves many thousands of times the amounts of substance that is contained at each given moment in all the organisms of the earth, plants and animals, or, as we say, in all the living substance of the planet.



It will be remembered that in the light, green plants liberate oxygen from their leaves and absorb carbon dioxide. The oxygen of the air, thus formed, oxidizes the plant remains and some rocks, and is consumed by animals during respiration.

In plants, carbon dioxide is transformed into carbohydrates, proteins, and other compounds. Imagine for a moment what would happen if all organisms disappeared from the surface of the earth, from the seas and oceans, from the plains and mountains.

The oxygen would be combined with organic substance and would vanish from the atmosphere. The composition of the latter would change. There would be no more microscopic marine organisms with lime skeletons and, consequently, no more layers of limestone and chalk would be formed, and chalk mountains would no longer rise. The face of the earth would change completely.

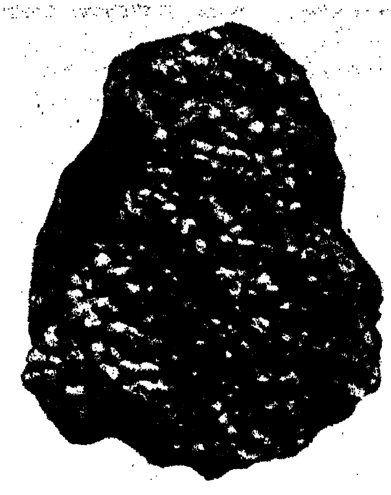
The geochemical activity of organisms varies extraordinary. Different organisms may take part in the most diverse processes.

In order to ascertain what geochemical part organisms play, we must first of all know their chemical composition. Organisms build their bodies entirely from the substances they, in some way or other, extract from their environment from water, soil and air.

It has long since been established that water H_2O is the chief constituent of all organisms, that the latter contain an average of about 80 per cent of it and that the plants have a little more water than the animals.

Consequently, oxygen constitutes the greater part of the organisms by mass.

Carbon plays an uncommonly important part in the structure of the bodies of organisms. It forms many thousands of various



General view of oolitic manganese

Microscopic picture of the structure of oolitic manganese ores. Photographed in reflected light

compounds with hydrogen, oxygen, nitrogen, sulphur and phosphorus which in their turn build the proteins, fats, carbohydrates and the bodies of organisms.

Carbon dioxide is the main source of these carbon compounds in living substance. The organisms, furthermore, contain considerable amounts of nitrogen, phosphorus and sulphur in the form of complex organic compounds.

Finally, the organisms always contain calcium, especially in their skeletons, potassium, iron and other chemical elements.

At first it was believed that the ten or twelve elements found in the organisms in greater quantities were of exceptional importance to all organisms.

It turned out later that there were organisms which in addition to the most frequently encountered ten or twelve chemical elements concentrated now iron, now manganese, now barium, now strontium and now vanadium, as well as many other rare chemical elements. It has thus been found, for example, that silicon plays an important part in the life of flint sponges, microscopic radiolarians and diatomite seaweeds whose skeletons are formed from silicon oxide.

Iron bacteria concentrate iron in their bodies. Bacteria, which similarly concentrate manganese and sulphur, have also been discovered.

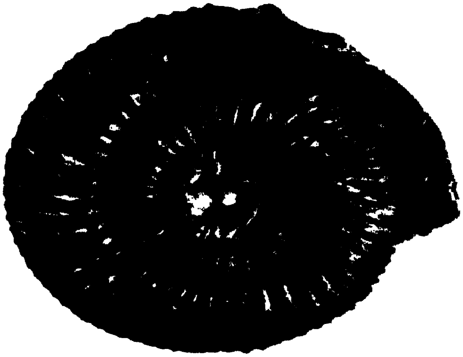
Barium and strontium have been found instead of calcium in the skeletons of some marine organisms.

Certain organisms, for example marine invertebrate tunicates, extract and accumulate atoms of vanadium from sea-water and sea-silt which contain only negligible traces of this element.

After the death of these organisms, vanadium concentrates in marine sediments.

Other organisms as, for example, seaweeds, extract from sea-water the iodine which the latter contains in only millionths of one per cent. The iodine is then deposited with the remains of the seaweeds on the sea bottom. Iodine-containing mineral waters are later formed in the rock composed of these deposits. We extract iodine from ground waters by drilling deep into the rock where there was once the sea.

The geochemical role of these concentrator-organisms is enormous.



Ammonite shell that has changed into marcasite (FeS_2) mineral. Environs of the city of Ulyanovsk on the Volga

The more perfect the techniques of investigating the composition of organisms, the greater the number of chemical elements we find in them, even if in very small quantities, to be sure.

At first it was even assumed that the silver, rubidium, cadmium and other chemical elements found in organisms were only accidental impurities, but it has now been firmly established that the organisms contain practically all the chemical elements. The only question is, how much of these elements the different organisms contain. It is precisely this question that occupies the scientists' minds today.

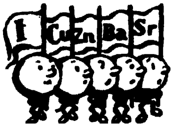
We can say beforehand that the composition of the organisms does not in any way reiterate the composition of their environment—the rocks, waters and gases put together.

For example, the soils and rocks contain considerable amounts of titanium, thorium, barium and other chemical elements, but we find many thousands of times as little titanium in the organisms as we do in the soils, etc.

On the other hand, the soils and waters contain little carbon, phosphorus, potassium and other chemical elements which accumulate in organisms in much greater quantities.

From the geochemical point of view it has now become clear that the main mass of the body of organisms is built of the chemical elements, which under the conditions of the earth's surface, i.e., the biosphere (the region where the organisms live on our planet) form mobile compounds or gases. In point of fact, CO_2, N_2, O_2 and H_2O are all mobile gases or liquids accessible to the organisms in the process of their life.

Iodine, potassium, calcium, phosphorus, sulphur, silicon and many others easily form water-soluble compounds.



MICROELEMENTS

But then titanium, barium, zirconium and thorium do not form water-soluble and, consequently, easily shifting compounds in the biosphere though they are found in the soils and rocks in sufficient quantities. They are less accessible or entirely inaccessible to organisms which do not accumulate them but contain them in unproportionally small amounts.

The organisms also contain very little of the chemical elements of which there is not enough in the biosphere, for example, radium and lithium.

The chemical elements found in organisms in very small quantities, about hundredths of one per cent and less, are often called microelements.

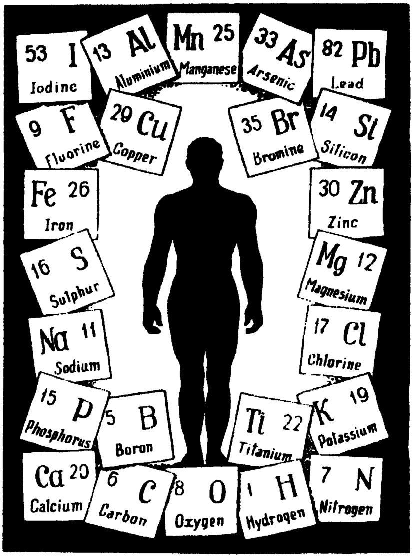
It has now been recognized that the microelements play a very important physiological role. Many microelements form part of physiologically important substances of organisms: for instance, iron is a constituent of the haemoglobin of the blood, iodine forms part of the hormone of the thyroid gland of animals, and copper and zinc are components of animal and plant ferments.

We could draw up a map of the anatomical structure of organisms indicating the organs and tissues in which the chemical elements are concentrated. But we are now concerned only with the geochemical role of the organisms.

We must agree that various organisms discharge different geochemical functions depending on their ability to concentrate particular chemical elements or, in other words, depending on their chemical-element composition.

"Calcium" organisms from whose skeletons limestones are formed also participate in the geochemical history of calcium in the biosphere; the organisms that concentrate silicon, vanadium and iodine play an important part in the history of these atoms.

We are facing the problem of studying the influence of organisms on the geochemical history of various atoms in the biosphere, of estimating this influence and of utilizing it.



Man is made of the same chemical elements as inorganic nature

It is already possible to find deposits of metals by observing the nature of the vegetation in a given place and by finding the plants known as the concentrators of these metals. An ore lying under a soil cannot help polluting the soil. The content of nickel, cobalt, copper and zinc increases in such soil and, consequently, also increases in plants.

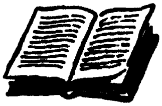
We now, therefore, analyze the content of these elements in plants. If the content is high, we dig ditches and bore holes. It is in this manner that some zinc, nickel, molybdenum and other deposits were discovered.

Organisms—plants and animals—have grown "accustomed" to certain concentrations of particular chemical elements in the environment, i.e., in the waters, soils and rocks. Wherever there happens to be less or, on the contrary, more of them, the organisms respond by a change in form and growth. Iodine deficiency in the soils, waters and foods in some mountainous regions is responsible for endemic goitre in man and animals, while calcium deficiency causes the bones to be brittle, etc.

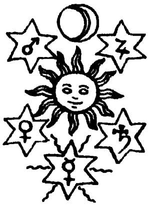
All this shows the close interdependence between the so-called dead nature and living substance.

They are connected by the common history of the atoms of the chemical elements.

The better and more extensively we know the history of the migration of chemical elements—atoms—on earth, the clearer and more precisely will we know the geochemical activity of living organisms and for this we must know, first of all, their quantitative chemical-element composition.



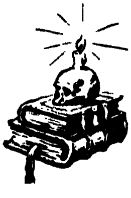
ATOMS IN THE HISTORY OF MANKIND



In tracing the history of the discovery of the chemical elements, we run into strange and surprising things. Man learned about the first elements in passing, without thinking of them, without even suspecting that he had mastered something which to a keen mind would reveal the most important secrets of nature. The idea acquired in practice that simple substances lie at the basis of the structure of all matter penetrated into man's consciousness slowly and with great difficulty.

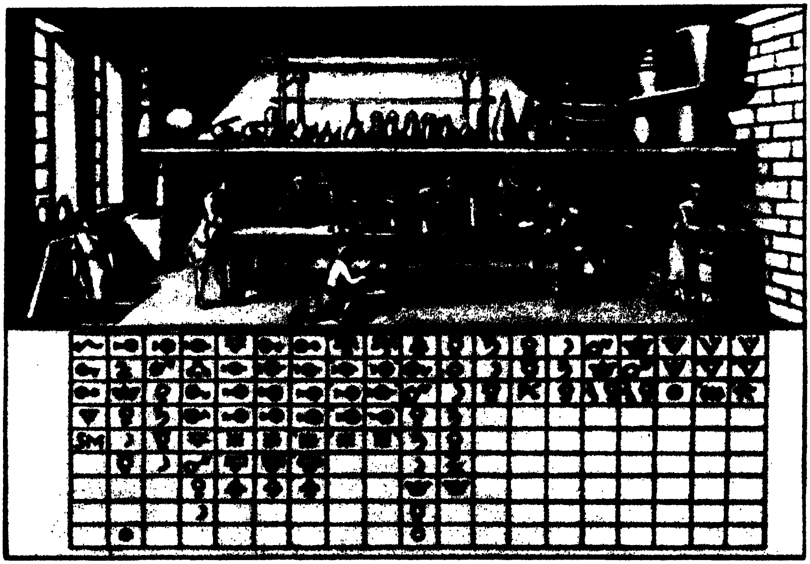
Alchemists did not know any methods for distinguishing a simple body from a complex body, but they knew metals and certain substances, for example, arsenic and antimony. The heights of alchemical wisdom are set forth in the following note of an alchemist:

> Like the planets up in heaven,
> Metals also number seven:
> Copper, iron, silver, gold,
> Tin and lead, to smelt and mould
> Cosmos gave us: listen further:
> Fiery sulphur was their father,
> And their mother — mercury:
> That, my son, is known to me!



For some time the alchemists, and later also chemists, called the metals by the names of planets: gold — Sun, silver — Moon, quicksilver — Mercury, copper — Venus, iron — Mars, tin — Jupiter, lead — Saturn. Arsenic and antimony were not considered metals, though their properties to oxidate and sublimate when heated were very well known.

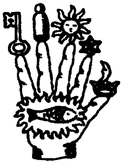
Regrettably the alchemists often camouflaged their recipes by incongruous and sometimes hardly understandable allegories.



Chemical laboratory in the 18th century. The table below shows the conventional symbols used by scientists of that time to designate various chemical elements. The top symbol in the first column stands for acid, the symbol at the bottom of the second column signifies gold, etc.

Here, for example, we have the "philosophical hand of alchemists." In the palm of the hand you see a fish — symbol of mercury, and fire — symbol of sulphur. A fish in fire — mercury in sulphur — was, according to the alchemists, the primary source of all types of substance.

The five main salts sprang from the combination of these elements like the fingers grew out of the hand: the symbols of these elements are at the fingertips: the crown and moon were the symbols of saltpetre; the six-pointed star represented iron vitriol; the sun signified ammonium chloride; the lantern indicated alum; the key stood for common salt.



It is now clear that when the alchemist wrote: "When you take the king you must boil him..." he meant saltpetre, and when he put a "pound of the long finger" into his retort, he was thinking of ammonium chloride.

The alchemists also knew each metal had its respective "earth" or "lime" and were able to extract these "limes" (or as we now say "oxides") from all metals by means of acids. But they thought these "limes" were the simpler bodies, while the metals were compounds of "limes" with "phlogiston," a special volatile fire-principle.

It required the genius and industry of Lomonosov and Lavoisier to prove that it was, contrariwise, "mercurial lime" that was a complex body consisting of mercury and oxygen, the gas just discovered by Priestley, and that the weight of this gas exactly equalled the addition in weight of the "mercurial earth." The time of this discovery (1763-75) is rightfully considered the beginning of modern chemistry and of the collapse of the alchemical fantasies which had long impeded the scientific study of nature.

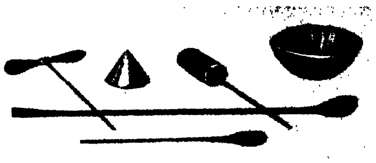
1775

Several dozen elements were already known by this time: Brandt discovered phosphorus as early as 1669, while cobalt and nickel were discovered in the middle of the 18th century, and man learned to produce zinc from the "zinc earth." Finally, in America in 1748, Antonio Ulloa described a new metal, which looked like silver and which turned out to be platinum.

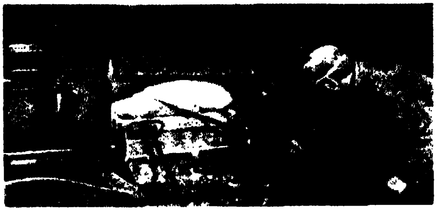
But a real revision of all "simple" bodies began only in the last quarter of the 18th century and in the beginning of the 19th century. Oxygen and chlorine were discovered in 1774, while in hydrolyzing water by the current of galvanic cells ten years later Cavendish discovered hydrogen and ascertained the composition of water.

The subsequent discoveries of elements proceeded regularly: new natural bodies were broken up into their constituents. New elements were found in a number of cases. Manganese, molybdenum, tungsten, uranium, zirconium and other elements were discovered in this manner.

In 1808, Davy perfected electrolysis which showed its potentialities in the hands of the Russian scientist Yakoby who boosted the current and learnt to protect the electrolysis products from oxidation by means of kerosene and mineral oils. It was thus that the alkali metals were obtained in the pure state: potassium, sodium, calcium, magnesium, barium and strontium were thus discovered. Fourteen elements were



Chemical utensils made of tantalum. It is as durable as platinum and cheaper



Furnace for smelting tungsten ores

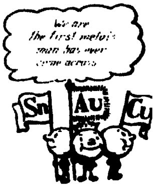
discovered in the fourteen years, between 1804 and 1818 (iodine, cadmium, selenium and lithium were discovered in addition to those we have already mentioned). These were followed by bromine, aluminium, thorium, vanadium and ruthenium. Then came a break; the old methods had already exhausted their potentialities and new methods were required.

Only when spectral analysis was discovered in 1859, did the scientists find new elements; these were elements closely related in properties to those formerly studied and could not be distinguished from them by the old scientific methods. The elements discovered were: rubidium, cesium, thallium, indium, erbium, terbium and some others. When D. Mendeleyev discovered his famous law in 1868 he already knew 60 elements.

From then on science knew of the existence of particular elements. It turned out that each element had its own place in the Periodic Table and that the total number of all elements was limited, while the vacant boxes represented the as yet undiscovered elements.

Mendeleyev predicted the principal chemical and physical properties of three of them eka-aluminium (box No. 31), ekasilicon (box No. 32) and ekaboron (box No. 21). His prediction was brilliantly confirmed when these elements were discovered. Ekaboron was named scandium, eka-aluminium was given the name of gallium and ekasilicon was called germanium.

You must not think, however, that man learned about the elements frequently encountered in the earth's crust first and about the rare ones later. Nothing of the sort. For example, there is very little gold, copper and tin in the earth's crust, but at the same time these were the first metals man had learned about and used for various purposes. Moreover, the earth's crust contains an average of several millionths of one per cent tin, a few ten-thousandths of one per cent copper and only one or two ten-millionths of one per cent gold.


We are the first metals man has ever come across
Sn
AU
Cu

The most abundant elements in the earth's crust as, for example, aluminium which constitutes 7.5 per cent of it were discovered very late. Aluminium was still considered a rare metal as recently as the beginning of the 20th century.

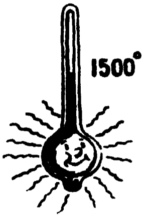
The reason is that it all depends upon how easily the metal is formed in its native state and how frequently accumulations in which this metal dominates, i.e., so-called "deposits," are encountered.

It was the tendency of the metals to accumulate in one place, that facilitated their discovery and utilization for the needs of man.

As each new element is discovered chemists are the first to begin studying its properties in the laboratory. This is, so to speak, the first acquaintance. At this time chemists look for the peculiarities of the elements, for its distinguishing, original features.

Isn't it curious, for example, that the specific gravity of lithium is 0.53, so that this metal floats even in benzine? Osmium, on the other hand, has a specific gravity of 22.5, so that it is 40 times as heavy as lithium. Is it not strange that gallium melts at only 30° C., but that it can hardly be brought to boiling, because it boils at 2,300° C. and this is well beyond the high temperatures ordinarily used in engineering? "What is so curious or strange about it?" you will ask. Let me try and tell you.

I shall tell you about gallium first. When engineers and chemists use high temperatures in laboratories and at factories, they always want to know the temperature to which the material or the article are heated. Of course, they must measure the temperature, first of all. But the trouble is that temperature is easily measured only up to 360° C.; it is much harder to measure higher temperatures because mercury boils at 360° C. and mercury thermometers just won't do. But here we have gallium, which will do. If we take refractory quartz-glass and fill the thermometer with molten gallium, we can measure a temperature of nearly 1,700° C., and gallium doesn't even feel like boiling. If we find more refractory glass, we shall be able to measure temperatures of up to 2,000° C.



Now about weight. Weight is the force with which a body is attracted to the earth. Weight resists motion, speed and ascent to unknown heights. But man wants to move fast along the earth and to fly in the air like a bird. For this we must conquer gravity, and man searches for light and strong structures, for light and strong materials. Two metals have proved especially suitable: aluminium with a specific gravity of 2.7 and magnesium, whose specific gravity is only 1.74.

Most of the parts of a modern plane are made of aluminium or, to be exact, from its alloys with copper, zinc, magnesium and other metals. However, aluminium has not won its dominating position all at once, but in a stubborn struggle for the improvement of its qualities: strength, hardness, resilience, and resistance to fire and oxidizers. When the difficulties of obtaining metallic aluminium were overcome, it conquered the kitchen first. Light and clean unoxidizable pots and pans, spoons and cups used up its first reserves. In the beginning engineering had made no use of it: it seemed this soft, not particularly strong, non-soldering and fusible metal could not be good for anything else. Aluminium conquered the world only when duraluminium, a hard alloy was produced by "kitchen methods." Various metals were added to aluminium in the crucible one after another, and each new alloy was tested for strength and other qualities.

Moscow. Krymsky Bridge built of duraluminium

Nobody could understand at that time why four per cent copper, 0.5 per cent magnesium and insignificant admixtures of other metals changed the soft and pliable aluminium into duraluminium, a strong metal capable of being tempered like steel. The remarkable properties of duraluminium do not manifest themselves at once, and this considerably facilitates and simplifies its machining. After tempering duraluminium remains soft for a few more days. During this time it "gathers strength" while the copper particles, which form the skeleton of duraluminium, shift within the alloy. But there are other alloys which are in some respects even better than duraluminium. Such, for example, is the Russian kolchugaluminium which is stronger than duraluminium.

The production of duraluminium and other light alloys is of tremendous importance to all types of transport. Cars of the underground railway or tramcars built of aluminium weigh one-third less than those made of steel. In the steel tramcar there are 400 kilograms of dead weight per passenger place, but with the metal parts of the tram manufactured from aluminium the weight per passenger place is reduced to 280 kilograms.

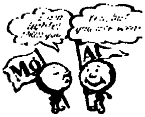
A few words must here be said about magnesium. The history of this metal is very curious; we can say it was discovered twice. It was discovered for the first time by Davy and since then it had been considered one of the most useless metals for over 100 years. It was used only for Christmas tree pyrotechnics in the form of ribbons and powder. But in the 20th century it was found that this "toy" metal possessed such remarkable properties that its utilization might cause a veritable revolution in various branches of engineering.

Aluminium has given man real wings. But it is not enough for man just to fly; he must fly as far as possible. And if the weight of the metal of which the plane is built is reduced by, say, 20 per cent it means an extra ton of fuel and, consequently, additional thousands of kilometres in the air. But where can we find a lighter metal than aluminium?

This is when man remembered magnesium because of its specific gravity of 1.74, i.e., 35 per cent lower than that of aluminium. Magnesium, however, does not have the qualities required for a structural metal, i.e., it is not strong enough and does not resist oxidation; it reacts even with boiling water, it deprives the latter of its oxygen and is transformed into a white powder magnesium oxide. In the air it burns better than wood. Designers and chemists did not lose heart, however, for they knew that alloys were the thing that would help them find the metal with the requisite properties. As a matter of fact, it has turned out that the slightest additions of copper, aluminium and zinc rob magnesium of its combustibility and impart to it the strength of duraluminium. All the alloys containing over 40 per cent magnesium are called "electrons." In addition to magnesium, the electrons include aluminium, zinc, manganese and copper.

Furnace for production of metalli molybdenum

And now in the 20th century magnesium was discovered for the second time and it immediately won a permanent place as an aircraft-building metal. It is especially widely used in aircraft engines. Their parts made of magnesium alloys are very strong and tireless.



Do metals ever tire? Unfortunately, they do. By contracting and expanding hundreds of thousands of times a steel spring loses its resiliency, becomes brittle and breaks—it "tires." In "aging" the shaft of a motor cracks. Engineering has discovered that some alloys are "tireless"; in these alloys the atoms of the different metals fit each other so well that despite all the shocks they get they never come apart. Such are the magnesium alloys. Naturally, it is not only aircraft-building where magnesium can be utilized. It is also widely used in automobile-building. Machine-tools and machine parts made of magnesium alloys are notably strong and light: they are from five to six times as light as the same things made of steel and are as strong, and sometimes even stronger.

Magnesium is a very abundant metal in the earth's crust and is found everywhere. Like iron it easily accumulates in large quantities and is not hard to mine. Considerable amounts of it are contained in seawater and in salt-lakes, for instance, in the Sivash waters off the Crimean coast.

The principal magnesium ore is carnallite ($KCl \cdot MgCl_2 \cdot 6H_2O$), and the Soviet Union has plenty of it. In the Solikamsk deposits large reserves of it lie in layers 100 to 200 metres deep. In mines carnallite is blasted by ammonal, cut and then brought to the surface.

Testing tungsten contacts in a special laboratory

On the surface it takes a lot of work to separate the magnesium from the chlorine with which it is very closely bound. For this purpose carnallite must be melted and direct current passed through it. The electricity breaks the bonds between the magnesium and chlorine, and the white metal runs in lively streamlets into the moulds.

The time has now come for magnesium to be extracted from seawater which contains 3.5 per cent salts and of which magnesium constitutes one-tenth. One cubic metre of sea-water, thus, contains 3.5 kg. of metallic magnesium.

The extraction of magnesium is very simple: filtered sea-water is poured into reservoirs and slacked lime is added with the result that magnesium hydroxide precipitates in the form of lees; the water is then poured off. The precipitate is dried on filters, neutralized by hydrochloric acid and completely dehydrated. The magnesium chloride obtained is electrolyzed in a molten state at approximately 700 C., like carnallite. This is all there is to the process.

But magnesium is not only a structural metal. Engineering has not forgotten its ability to burn and develop an enormous temperature of up to 3,500 C. Magnesium is an important constituent of special bronzes, while magnesium and aluminium dust forms the most powerful mixture for incendiary bombs. Industry needs a lot of magnesium and the latter has a brilliant future.

But let us come back to aircraft. There is one more "flying" metal, and aircraft-builders are only just beginning to make use of it. This metal is beryllium. It has a specific gravity of 1.84, but it is stabler and "stronger" than magnesium.

Beryllium alloys excel all the alloys used in aircraft-building until now. Tools made of these alloys work noiselessly and produce no sparks.

Beryllium enhances the qualities of magnesium alloys and makes them particularly strong and unoxidizable. A very slight addition of beryllium to magnesium does away with the necessity of protecting metallic magnesium against oxidation during teeming.

But the question arises: aren't there any still lighter alloys?

Let us recall the metal known as lithium. Its specific gravity is 0.53, i.e., like that of cork, but added to aluminium and magnesium alloys in small amounts it makes them especially hard.

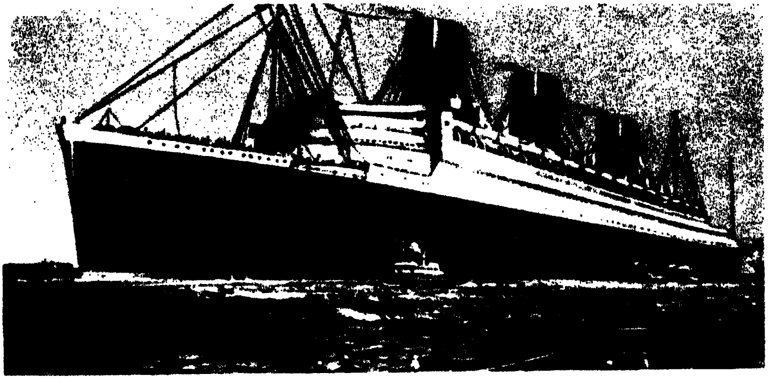
It is a matter of regret that no stable alloys with a large amount of lithium have been found as yet. But they are worth looking for because lithium is an abundant metal: there is as much of it in the earth's crust as there is zinc, and it occurs in large quantities in certain deposits in the form of spodumene minerals and in lithium micas.

I am also a "flying" metal!
Be

Hence, if the alloys of lithium and beryllium, for instance, were found suitable lithium could be procured in sufficient quantities. The studies of lithium alloys have not brought any constructive results as yet, and these alloys still constitute an important problem of the day.

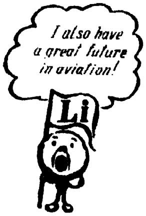
Lithium is found in mineral waters and physicians ascribe especially curative properties to lithium-rich waters (as, for example, the Vichy waters in France). But the prospects for obtaining a light, durable and non-oxidizable metal for aircraft are still the most tempting.

However, the light metals and alloys are still far from having replaced the ferrous metals (iron, steel and their alloys) in the transport and in many other branches of industry. We shall now say a few words about these "old-timers" who are still hale and hearty, however, and who produce ever new alloys of excellent quality.



Ocean liner with hull built of molybdenum steel

If we take into account all the complex, so-called alloyed steels, we shall see that they consist of a series of closely related metals – iron, titanium, nickel, cobalt, chromium, vanadium, manganese, molybdenum and tungsten. All these alloys are basically "steels," i.e., they consist of carbonaceous iron whose qualities have been essentially improved by "alloying" or by the addition of a rare metal.


I also have a great future in aviation!
Li

By successively replacing larger and larger parts of the iron with rare metals technologists have produced alloys which no longer contain any iron. Such, for instance, is stellite which consists of tungsten, chromium and cobalt. This alloy is the father of the now well-known superhard alloys which have given engineering the unprecedented metal-cutting speeds, first, of 70 to 80 and now of hundreds of metres per minute.

Tungsten has given rise to superhard alloys and the powerful technique of metal-cutting. Tungsten and molybdenum have produced hundreds of new grades of uncommonly strong, fireproof, armour, spring, shell, armour-piercing and other steels.

There is scarcely a branch of engineering that has not undergone any radical changes connected with the discovery of the properties of such rare metals as tungsten, molybdenum, etc.

Climax, molybdenum deposits in the Rocky Mountains. Here layers of molybdenum are deposited in granites. Right concentration factory

Incidentally, they have already outlived the term "rare." If we consider their content in the earth's crust we shall find there is twice as much molybdenum and seven times as much tungsten as there is lead in it. Then why call them rare? In industry they are also becoming common, while their output is increasingly growing and is catching up with that of the usual "non-rare" metals.

Steel alloys containing molybdenum are used for the manufacture of gun barrels and gun-carriages. Manganese-molybdenum steel is used in armour and in armour-piercing shells.

Automobile and aircraft designers make three basic demands on metal: maximum resilience, great viscosity and high resistance to protracted shaking and frequent shocks. Increased molybdenum consumption in recent years, especially in combination with chromium and nickel, is due precisely to its extensive use in shafts, connecting rods, support machinery, aircraft engines and pipes.

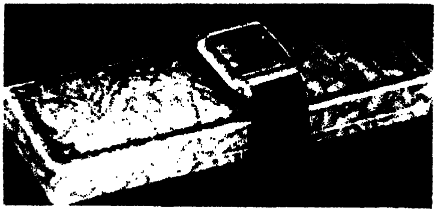
High-quality grey cast iron is another form of molybdenum consumption. A negligible addition of 0.25 per cent molybdenum enhances the physical properties of the cast iron, particularly, its resistance to bending and tension, as well as its hardness.

Considerable amounts of tungsten and molybdenum are used by electrical engineering in the form of thin wires in vacuum valves. Electric bulb filaments are made of tungsten. Tungsten melts at 3,350° C. which is the highest melting point among the metals. Carbon is the only element that melts at a still higher temperature, i.e., 3,500° C. Two elements have melting points very close to that of tungsten: tantalum 3,030° C. and rhenium 3,160° C. The little anchors that hold the incandescent tungsten filaments in electric bulbs are made of molybdenum whose melting temperature is 2,600° C.

Today I am more expensive than tantalum!
Nb

Thus we can see that it is not enough to discover an element; we must study it and find the quality in it that is particularly valuable for manufacture; the element is then discovered for the second time, as it were, and it becomes useful and necessary. Take, for example, the tungsten contacts in automobile motors where a tungsten plate 0.1 millimetre thick ensures the electric contact in the interrupter and works faultlessly for hundreds of hours.

Isn't the example of niobium instructive? Niobium was considered a useless element that "polluted" tantalum together with which it is usually found. When it was discovered, however, that steel with an



Niobium in watch case

admixture of niobium was an excellent material to be used in electric welding of steel, because it produced an unusually strong seam, niobium became as necessary as tantalum.

There is no end to the introduction of ever new elements into industry, nor will there ever be, because technical progress is unlimited. Both chemists and geochemists play an honourable part in it.

But how does technical progress affect the earth which provides all the substances required by engineering? Man strives to reshape the earth's crust in his own way taking all he wants from it and paying no heed to the fact that whatever he takes is irreplaceable. Isn't man exhausting the earth?

Mining ore by excavator

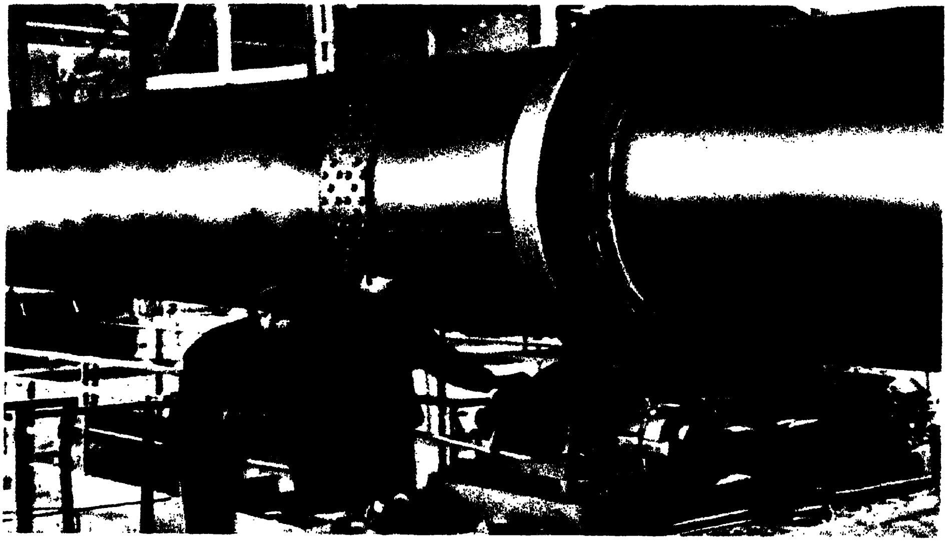
These are the questions that occur to us when we watch the general development of mankind. There is one more circumstance that impels us to pose this question and that is the ever increasing amounts of useful products annually extracted from the interior of the earth.

A mining engineer told me he had once stopped at a little house near a mountain of magnesite. Within two or three weeks the mountain vanished: it had been hauled away to a cement plant.

Suffice it to look at the mountains of slags thrown out by our iron and steel mills to understand that man's activity is a geological factor that is reshaping the earth's crust.

One of the most important problems of the world chemical economy is the fate of carbon in which man has especially vigorously interfered. Carbon is distributed in nature in three forms: in organic substance, in accumulations of coal and oil and in an oxidized state, i.e., in the form of carbon dioxide in the atmosphere and in the waters of the rivers and oceans. But the greatest amount of carbon dioxide is found in combination with calcium in hard limestones.

The atmosphere contains more than 2×10^{12} tons of carbon dioxide and, consequently, over 600,000 million tons of carbon. Man annually extracts more than 1,000 million tons of coal and hundreds of millions of tons of oil. He burns both, transforming them into carbon and carbon dioxide. More than 3,000 million tons of carbon dioxide is, thus, annually liberated into the atmosphere and in 200 to 300 years its quantity should have doubled if it were not for the contrary processes, i.e., its dissolution in the ocean and its consumption by plants.



Rotating furnace for calcinating carbon materials; installed in the electrode shop of an aluminium plant

By utilizing the carbon of the coal layers man aids in dispersing this element on so large a scale that his activity assumes the scope of real geological transformations.

No less imperiously does man interfere in the fate of metals: he has about 1,000 million tons of iron and iron wares in circulation; the metal is in an unstable native form and it is being oxidized.

During a certain period of time oxidation depreciates nearly as much iron as is produced during the same period so that the accumulation of iron cannot outstrip its dispersion.

With gold the situation is somewhat better: about one ton of it is used up annually for reagents and for gold-plating and is dispersed by wear, which is a lot less than is produced (about 600 tons).

And such metals as lead, tin and zinc are extracted by man from accidental natural accumulations in the earth's crust, the so-called deposits, in order to become irretrievably dispersed in the process of their utilization.

Man's agricultural and engineering activities are quite comparable in their scope to the influence of the elemental processes.

The tilling of the superficial layer of the earth (soil) for agricultural needs is of tremendous geochemical importance since more than 3,000 cubic kilometres of it are annually exposed to the vigorous action of the atmospheric waters and the air.

The cultivated plants take an enormous amount of mineral substances out of the soil, namely, 10 million tons of phosphoric anhydride and 30 million tons of nitrogen and potassium. This is many times the amount introduced into the soil during fertilization. The extracted elements enter the cycle of substances in the animal world and are finally dispersed.

By his agricultural and technical activities man disperses substances. More than one cubic kilometre of rocks is annually extracted from all mines. This figure will have to be doubled or even trebled if we add the construction of dams, irrigation canals, etc.

The amount of slags annually produced by all of the world's metallurgical furnaces probably also comes close to one cubic kilometre. And just think of the waste-products of the chemical industry brought out by man on to the surface of the earth!

If we compare these figures with the 15 cubic kilometres of sediments annually carried away by all the rivers from the earth's surface we shall

Laboratory for testing the physical properties of minerals

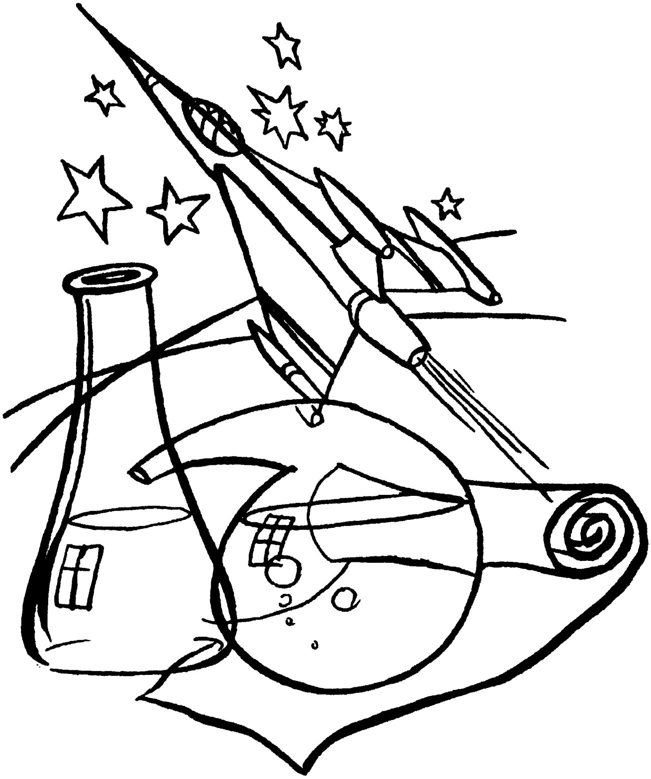
have to acknowledge that human activity is as serious a factor as that of the rivers.

And what about the art of building and the quantities of stones and cement consumed by it annually! The intensive construction of cities in the U.S.S.R. uses up more than 1,000 million tons of various building materials every year.

Man is reshaping nature at an ever increasing rate. If we consider the total reserves of metal in the earth we shall find them large enough to make any talk about exhausting them premature. But not all of these reserves can be made use of because industry can actually avail itself only of the rich accumulations of any particular metal, and there are not so many of them.

The real reserves of many metals scarcely meet the requirements of industry. Legions of geological prospectors and geochemists must therefore search hard for metals in order to satisfy the ever growing industrial needs.

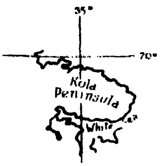
PART FOUR



PAST AND FUTURE OF GEOCHEMISTRY

FROM THE HISTORY OF GEOCHEMICAL IDEAS

I do not want the readers to get the impression that everything is clear, everything is known, and that all elements have been discovered. I shouldn't want them to feel that we have acquired our knowledge without any difficulties, that the science of the chemistry of substance has grown up of itself without a struggle or searches, without hard and persistent work.



No, my friends, the past of science teaches us that thousands of people have struggled for its truths for many hundreds of years, that they have made mistakes, searched for new ways, worked day and night in old basement laboratories, fought ignorance and the oppression of the church and monasteries and battled for an understanding of nature.

And this understanding has not come all at once.

I remember standing on the shore of Lake Vudjärv on Kola Peninsula. Before us lay a city, and automobiles kept running down the highway towards the city. It was only with difficulty that I was able to imagine the wild and forbidding tundra, almost lifeless and cold as I had seen it for the first time just ten years before.

Looking at the city with its large population, the straight wide highways and the speeding lorries, the newcomer can hardly believe that only recently this was the remote tundra. But has it occurred to him that explorers wandered around here searching for ores and minerals only a few years ago? Has he thought of the hard work and deprivations that the prospecting for the resources, concealed in the severe tundra, required in order to call this region to life?

It is the same in science; when we study the achievements of modern scientific thought and view the tempting prospects of the near future from the conquered heights, we forget the hardships, the time and the sacrifice it took to clear up the dense forests of ignorance.

The science which we call geochemistry is the history of the chemical elements of our planet. It could take final shape only of late when not only the idea of the atomic structure of matter has become a reality, but when science has also penetrated deeply into the structure of the atom and has learned its essential features.

Modern geochemistry dates from the beginning of the 20th century. In a broad sense, however, geochemical ideas, concerned with chemical elements, chemical composition of minerals and the signs for finding ores and minerals, have existed and developed in the course of the last three or four centuries.

Mineralogy and chemistry, which have gone through many stages in their development before reaching their present state, have formed the basis of geochemistry.

In the struggle for existence man learned as early as pre-historic time to find the stones he could use for weapons and tools; already then he was very much impressed by the beauty of the precious stones.

At a higher stage of development man began to wonder about the earth and how it had come to be. Legends about the origin of the world, or so-called cosmogonics, began to come into being and were slowly and gradually replaced by more positive ideas. The most civilized ancient peoples on the Mediterranean coast already had rather well developed conceptions expressed by such thinkers as Democritus, Aristotle and Lucretius.

The ideas of Aristotle, the greatest naturalist of antiquity (384-322 B. C.), are of particular interest to us, since he believed the earth to be a sphere. According to this thinker, the universe had the shape of a sphere and the earth as the heaviest body was in the centre; it was surrounded by water and by the air mantle. The lightest element was fire, and then came ether. The earth, air, water, fire and ether constituted the five elements. Despite the erroneousness of many of Aristotle's ideas, he exerted an exceptionally great influence on the development of the natural sciences. Marx considered him the greatest thinker of antiquity who was able to generalize all of natural science of that time in his works.

Aristotle

Theophrastus (371-286 B.C.), Aristotle's pupil, was the first to list the minerals known at that time and to make an attempt at classifying them. He can be rightfully considered the founder not only of mineralogy, but also of the science of soils and plants.

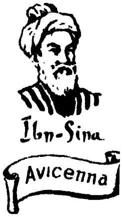
A remarkable work for its time, that of Pliny the Elder, the Roman investigator who died during the eruption of Vesuvius in 79 A.D., comes to the fore in the first century A.D. In addition to fantastic legends, this work conveys a lot of true information about minerals, whose names have partly been preserved to-date.

During the Middle Ages, the exact sciences did not develop in Europe. At that time the natural sciences and chemistry developed mainly in the East.

In the singular treatises of the Arab thinkers of the 9th and 10th centuries, we find indications of the coexistence of separate metals in nature. Thus, Luke Ben-Serapion in the foreword to his *Book about Stones* writes that "there are stones that are encountered together and stones that avoid each other; there are stones which are untrue to other stones, as there are stones which colour other stones."

The search for ores, their processing and the production of metals and alloys undoubtedly made man continuously wonder about the conditions under which chemical elements were found together. The generalizations about love and hatred between various substances which then came into man's mind were the first geochemical laws that have retained their significance.

The work of Avicenna, the philosopher from Bukhara (985-1037), is particularly interesting. The philosopher wrote a treatise on minerals in which he classified them as: 1) Stones and earths, 2) Combustible and sulphurous compounds, 3) Salts and 4) Metals.



Another outstanding scientist, Al Biruni (973-1048) of Khorezm, wrote a remarkable book in Arabic entitled *Complete Knowledge of Precious Minerals* in which he generalized all the mineralogical data of that time.

The works of alchemistry in Arabic, which made their appearance in the 9th century, are of great importance to the history of chemistry, since they were the first to set forth the problems of truly chemical methods of research.

The alchemists worked mainly on synthesis, i.e., they tried to obtain new substances from the ones they already knew. Alexandria was the cradle of alchemistry, whence chemical knowledge and skills penetrated into Syria. The Arabs borrowed alchemistry from the Syrians and brought it to Europe through Spain.

Alchemistry usually implies the deceptive art of making gold from various other metals. As a matter of fact medieval alchemists attempted mainly to ennoble the usual metals by trying to transform them into silver or gold. But these were not the only problems they were working on. They were also searching for remedies and the "philosopher's stone."

The unsuccessful endeavours to change the metals gradually forced the alchemists to find a new application for their art. Their attention was focused on the health of man and alchemistry became the handmaiden of medicine.

Though the alchemists were accused of quackery, they enormously benefited the development of chemistry, because they conducted endless chemical experiments, and despite the fact that their initial ideas were wrong, they sometimes achieved important results.

The famous philosopher Leibnitz wrote very well about the alchemists, saying: "These ordinary people have great imagination and experience, but their imagination is at variance with their experience. They cherish pure hopes, and this leads them to failure or makes them a laughing stock. And still such people not infrequently know more facts from their experience and observation of nature than many a respected scientist."

Came Renaissance. It signified a change for a new and higher stage of culture.

The first impetus to the development of mineralogy was the prosperity of the mining industry in Hungary, Saxony and Bohemia.

The remarkable works of Agricola (1490-1555), physician and mineralogist in the Saxonian mining centre, laid the basis for the exact and deep understanding of the objectives of mineralogy and geochemistry. His real name was Georg Bauer. He left many books which represent a summary of the knowledge of ore deposits of that time. His most remarkable books are *De natura fossilium* (1546) and *De re metallica* (1546). His classification of minerals is of a scientific character. It includes for the first time the idea of complexity of compounds, i.e., chemical principles. This system forms the basis of all subsequent mineralogical works up to and including the 18th century.

Prospecting for ore deposits. Picture taken from Agricola's book. 1556

Jons Jakob Berzelius (1779-1848), Swedish chemist and mineralogist, worked on the chemical analyses of minerals and was the first to give their real chemical classification; he was also the first to introduce the term "silicates."

Scientific societies and academies, especially the oldest academy—Academia del Cimento—which was founded in 1657, played an important part in the history of geology and mineralogy. The Royal Society was organized in London in 1662 and is the British Academy of today.

Scientific societies and large Kunstkammers became very popular at the end of the 17th and, especially, the beginning of the 18th centuries. The Swedish Academy of Sciences, and then the Russian, founded in 1725 in Petersburg, have played a tremendous part in the development of science.

In Russia, geochemical ideas were given their first vivid expression in the works of M. Lomonosov (1711-65)—*On the Structure of Terrestrial Layers* and *On the Birth of Metals.* Lomonosov was the first to suggest that metals and minerals migrated. "Metals move from place to place," was his brilliant conclusion. He gave rise to new ideas about minerals as products resulting from the life of the earth's crust, ideas which in the 20th century formed the basis of the new science of geochemistry.

Dozens of books and hundreds of articles were written about Lomonosov; the most prominent investigators, scientists, writers and poets devoted their best pages to the analysis of this giant of Russian thought and it is still impossible to exhaust this subject, because the genius of Mikhail Lomonosov, this Arkhangelsk *pomor* was so great and profound.

We can imagine the powerful figure of this Titan hardened in the struggle against polar nature, "with his noble stubbornness" because of which he would never yield to anybody or anything.

Courage, resolve and daring bordering on stormy fantasy, a thirst to know everything, down to the root of things and to the source of all sources, and a capacity for profound philosophical analysis in combination with a brilliant ability to conduct experiments, without which he could not think of science, were some of Lomonosov's traits. And whereas seven cities of antiquity debated the honour of keeping Homer's grave, more than a dozen different sciences and arts are fighting for the main heritage of Lomonosov: physics and chemistry, mineralogy and crystallography, geochemistry and physical chemistry, geology and mining, geography and meteorology, astronomy and astrophysics, regional science and economics, history, literature, philology and engineering. To be sure, Lomonosov was, as Pushkin was wont to say: a "whole university" in himself.

Lomonosov may not have been understood by his contemporaries, but new generations which he was so fervently teaching and to which he was making his appeal, were already coming into being.

> Come, Russian youths of piercing ken,
> From fertile fields and forests broad,
> To take the place of learned men
> Today invited from abroad.
> Blessed be your days for evermore;
> Strive on with neither doubt nor awe,
> And with your great achievements show
> That Newtons, Platos of our own
> And other men of world renown
> On Russian soil can also grow!

Two hundred years have passed since then, but only now are his brilliant foresight and daring theories being embodied into the greatest scientific truths before our very eyes, and his cherished dreams about the greatness and glory of our country becoming reality.

Lomonosov understood science not only as a mere description of phenomena, but as their explanation. He believed it was necessary to study not the bodies in themselves, but their internal structure and the causes of this structure, as well as the forces which acted inside substance. He knew that all of science in all its manifestations depended on the solution of the one great problem: that of substance, its structure and composition.

Mikhail Lomonosov, Russian scientist (1711-65). The first investigator in the field of geology to link up the problems of studying minerals and rocks with those of chemistry and physics. Founder of geochemical and physico-chemical ideas in Russia

Lomonosov came to the conclusion that substance consisted of separate particles which possessed special attraction, inertia and motion; some of them were smaller—these were the simple atoms; others were larger—these were the molecules. None of them was visible to the eye, and they were all in constant motion and rotation. Essentially, this remarkable inference fully corresponds to the modern atomistic world outlook.

Nearly half a century before the great French chemist Lavoisier, Lomonosov maintained that nothing could be lost in nature, thus, essentially, establishing the great law of nature, the law of conservation of matter and energy.

By gradually investigating the nature of the original particles through physics, Lomonosov began studying chemistry. Chemistry is a science about the changes occurring in the composition of a body, i.e., a science which depends on the phenomena of physics and mechanics.

In his brilliant *Word about the Benefit of Chemistry*, a paper read to a general meeting of the Academy of Sciences in 1751, he disclosed the grand prospects of the new chemistry; he rejected the old ideas of the alchemists born in their mysterious laboratories, and laid the foundation for the new edifice of chemistry, in which number and weight and the laws of mathematics prevailed. He carried his ideas into practice.

1752-1753

In 1748, after a struggle of many years, he, finally, organized on Aptekarsky Peninsula in Petersburg the first Russian scientific chemical laboratory where he kept exact records of measure, weight and proportions of substance.

In 1752-53 Lomonosov taught the first course in "physical chemistry" in the world. He said that "chemistry played an important part in all human affairs" and he worked persistently in order to satisfy the practical needs of his country. He produced a new composition of optical glass; after 3,000 experiments, he began to manufacture a coloured smalt for mosaics, built a special mosaic factory, studied the composition of the Urals minerals and worked on problems of saltpetre and phosphorus.

The first problems posed by Lomonosov before the new experimental laboratory included the preparation of pure substances. This led Lomonosov to the study of pure metals, salts and saltpetre, and the old lessons of technology and mineralogy were revived in a new form. For him a mineral was a mixture of primary particles and its properties depended on "the mutual union of the particles."

Like any other substances, stone had its own history of life and death and Lomonosov urged that natural minerals be studied by new methods.

He linked the conditions of mineral formation to geological processes; he endeavoured to divine these processes in the interior of the earth in the fissures of volcanoes filled with incandescent vapours of sulphur; on the surface he saw the genesis of stones in the remains of animals and plants. Thus, in the mind of Lomonosov, who combined in his person a naturalist, philosopher and chemist, stone came to life in the light of new ideas.

Here is what M. Lomonosov wrote in his remarkable book *On Terrestrial Layers* published in 1763:

"This is what the entrails of the earth are like; here we have layers and here veins of other substances which nature has produced in the interior. We must observe their different position, colour and weight and in our thinking use the ideas and advice of mathematics, chemistry and physics in general."

1838

This was no longer the old and tedious descriptive mineralogy, but a new science—geochemistry, i.e., chemistry of the earth. And as he had formerly built the foundation for the great edifice of physical chemistry on the borders between physics and chemistry for the first time in the history of scientific thought, he now laid the corner-stone of the new science on the borders between chemistry and geology, the science which at that time had no name as yet. Seventy more years were required before the word "geochemistry" first came off the lips of one of the most prominent naturalists in 1838; it was the Swiss chemist Christian Friedrich Schönbein (1799-1868) who four years later wrote:

"Several years ago I made a public statement of my conviction that we must have a geochemistry before we can speak about a real geological science which, obviously, must devote its attention to the chemical nature of the masses that constitute our earth, to the origin at least as much as to the relative antiquity of these formations and to the remains of the antediluvian plants and animals buried in them. We are warranted in saying that geologists will not for ever pursue the direction they are following now. In order to expand their science as soon as the fossils fail sufficiently to serve them, they will have to look for new auxiliary means and will then, no doubt, introduce mineralo-chemical methods of research into geology. The time when this will happen does not seem very distant to me."

And here the history of science tells us how a new idea and a new success resulted from the preceding development of thought.

Long and painstaking work with facts was required for extensive chemical regularities to be reliably generalized into geochemical laws, in order that from brilliant conjectures they might be transformed into firmly established and verified scientific generalizations.

The Russian scientist Dmitry Mendeleyev (1834-1907) had made an enormous contribution in this direction; by discovering the law of periodicity of the properties of chemical elements he laid a real foundation for the theretofore barren concept of the unity of the structure of the universe.

D. Mendeleyev began working as a chemist in the fifties of the 19th century when Russian industry started its vigorous development. Since Mendeleyev ardently loved his country he did not shut himself off from practice but engaged in it with the energy so typical of him.

He wrote about utilization of oil and coal as well as about their origin and reserves, invented smokeless powder, and studied the possibilities for the development of the iron industry.

He believed the ultimate aim of scientific studies to be "foresight and benefit."

Mendeleyev's chief work, the *Fundamentals of Chemistry*, was published in 1869, republished in eight editions during his lifetime, and repeatedly after his death.

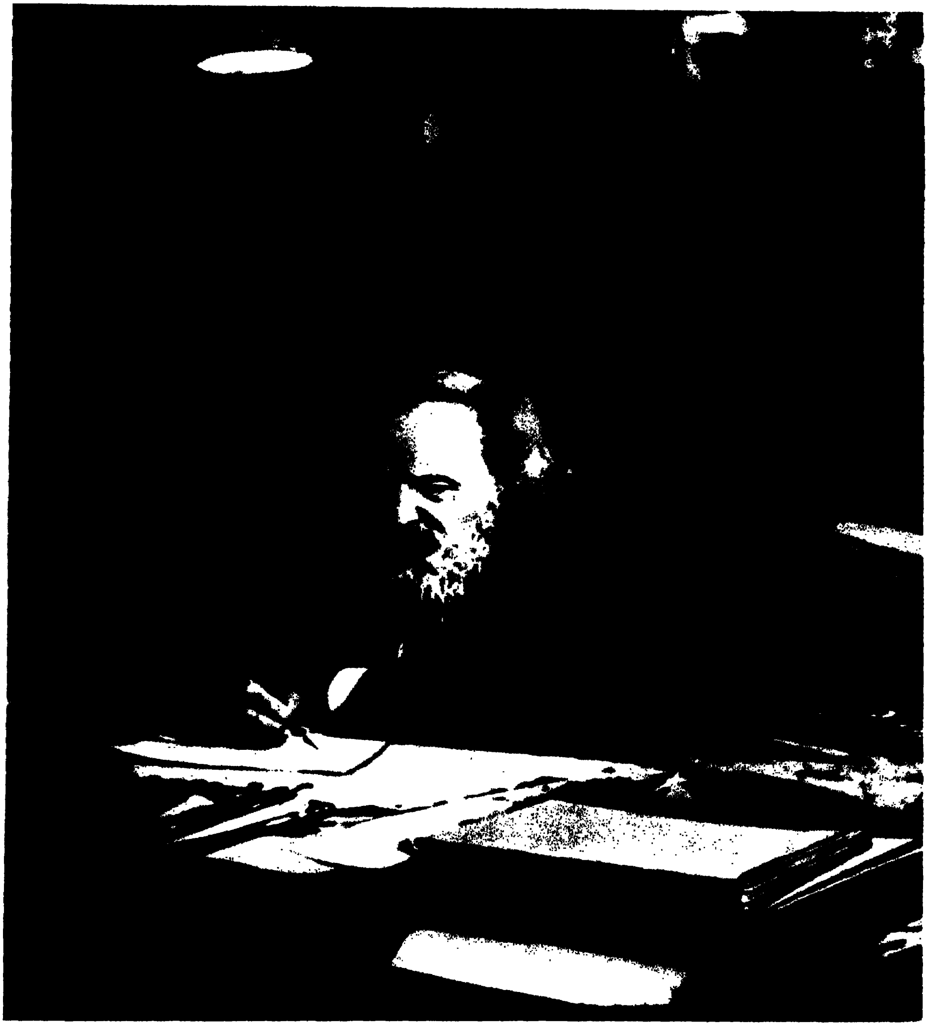
Mendeleyev considered this book his favourite brain-child. "This book contains my image, my experience of a teacher and my most cherished scientific thoughts.

"The *Fundamentals of Chemistry* contained my spiritual powers and my legacy to the children," he wrote in 1905.

The discovery of the periodic system of chemical elements undoubtedly charted a new course for the development of chemistry and brought Dmitry Mendeleyev world fame.

This law was given a remarkable appraisal by F. Engels. He said:

"Mendeleyev proved that various gaps occur in the series of related elements arranged according to atomic weights indicating that here



Dmitry Mendeleyev, Russian chemist (1834-1907). Creator of the periodic system of elements new elements remain to be discovered. He described in advance the general chemical properties of one of these unknown elements....

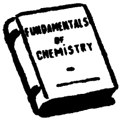
"A few years later, Lecoq de Boisbaudran actually discovered this element.... By (unconsciously) applying Hegel's law of transformation of quantity into quality, Mendeleyev achieved a scientific feat...."*

Mendeleyev predicted new chemical elements, corrected atomic weights and gave the right formulae for many chemical compounds.

He was the first to liken the atoms to celestial bodies—the stars, the sun and the planets; he assumed that the structure of the atom was similar to that of the celestial systems, i.e., like the solar system or the system of binaries.

For geochemistry the Periodic Law has been the basis for the systematic study of the laws governing the combination of chemical elements under natural conditions.

The law was discovered. But it required another 75 years, a long period of vast research, a period of struggle of different trends to explain it and demonstrate its purport and significance for our entire world understanding; it required numerous new experiments.



In establishing the closest relationship between chemical and physical phenomena, Mendeleyev put in practice the famous words of Lomonosov: "A chemist without a knowledge of physics is like a man who must grope in the dark. These two sciences are so closely related that neither can be perfect without the other."

Why has the Periodic Law of chemical elements played and will continue to play so important a part in the history of science? Because Mendeleyev's Periodic Table is very simple and represents a simple series of natural facts correctly combined with each other in a definite spatial, chronological, power and genetic relationship. There is nothing fabricated in it. It is nature herself. The real world of substances that surrounds us and is accessible to our perception is essentially a grand table unfolded according to long periods and divided into separate parts.

Of course, new theories will come into being and die, brilliant generalizations and new conceptions will replace the outdated ideas; the greatest discoveries and experiments will exceed by far all the past and will open up incredibly novel and extensive horizons. All this will come and go, but Mendeleyev's Periodic Law will always live and develop; it will constantly be rendered more precise and will serve as a guide in all quests.

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* F. Engels, *Dialectics of Nature*, Moscow, 1954, p. 90.

In his works, Mendeleyev appealed to us to continue developing the law.

In one of the introductions to the *Fundamentals of Chemistry* he wrote:

"With the knowledge of how freely and happily one lives in the sphere of science, I cannot but wish that many people entered this sphere and this is really why I am writing my book. It is for this reason that I cannot help reiterating the desire that the chemical world outlook which I tried my best to develop in the readers impel them to continue studying the science. The conscription of the young generation in the service of science should not frighten those who are aware of the urgent necessity for our country's practical activities in agriculture, industry and manufacture. Only when the truths are learned in their absolute purity, can they be applied in life."

All of Mendeleyev's works are imbued with this appeal to the young generation. His lectures were attended by students from all faculties. His word captivated his listeners and the auditorium was always crowded. The students came not to hear ready-made schemes, but to hear their teacher think and create.

In the 19th century studies of the chemical process related mineralogy to physical chemistry and gave scientists new and more precise knowledge of the regrouping of chemical atoms in the earth's crust.

This trend, prevailing in the last years of the 19th century, paved the way for geochemical ideas by requiring that the elements of which the minerals are composed be taken into consideration in analyzing the process of their formation. But geochemistry could not come into being as long as there was any vagueness in the idea about the atom itself, the element or crystal.

Only Mendeleyev's Periodic Law and the achievements of physics, especially of crystallography, made the atom a reality and the crystallographic grid actually a natural phenomenon, and linked the element and its properties to the structure of the atom.

The ground for the creation of geochemistry had been cleared but it still required a tremendous number of facts and observations, extensive experimental work had to be conducted in a number of institutes

where not hundreds but thousands of complex and difficult definitions outlined correct working methods. Only these new factual gains together with the theoretical advances of physicists and crystallographers have opened up new prospects before modern geochemistry.

This independent science, developed mainly by the efforts of Russian, Norwegian and American investigators, now aims at studying the atom and its fates under natural conditions.

Unlike the other geological sciences, geochemistry does not study the fates and properties of molecules, chemical compounds, rocks or their geological complexes; it studies the fates of the atom under the conditions of the earth's crust accessible to exact experiment; it studies its behaviour, the processes of its shifts, migrations, combinations, dispersion and concentrations. In doing this geochemistry

Academicians Vladimir Vernadsky (1863-1945) and Alexander Fersman (1883-1945), founders of the Russian school of geochemists must not only discover and outline the long and intricate history of each element in Mendeleyev's Periodic Table, but must also link this history to the properties of the atoms on which the vital fate of the elements depends.

Geochemistry was given an exact definition and development in our country, and Russian scientists have played a very important part in it. Soviet geochemistry has made such headway that it has quite deservedly won the most honourable place in world geochemical science.

The basis for the Russian school of geochemistry was laid at Moscow University by academicians V. Vernadsky and A. Fersman, the author of this book.

The chemists and geologists in the U.S.A., Germany and Norway developed their own school, but its work has been of a somewhat different and much narrower nature.

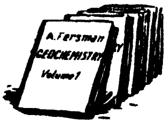
Frank Clarke (1847-1931), a Washington geologist, deserves special mention. He published his *Data of Geochemistry* in 1908. For 36 years Clarke collected chemical analyses of rocks and minerals and after a critical treatment of considerable factual material made general conclusions on the average chemical composition of various terrestrial rocks and of the earth's crust as a whole.

But Clarke did not regard his data as a basis for studying terrestrial processes.

The development of geochemistry was greatly influenced by the Norwegian scientists Johannes Vogt (1858-1932) and Victor Moritz Goldschmidt (1888-1947).

J. Vogt founded physico-chemical petrography which serves as the basis for studying magmatic processes and offers examplary opportunities for estimating the chemical composition of the earth's crust. By closely linking crystallography with the physics of solid bodies V. Goldschmidt developed the principles of modern crystallochemistry and contributed a great deal to the geochemistry of the deep shells of the earth's crust. The series of his papers on the *Laws of Distribution of Chemical Elements in the Earth's Crust* have won wide renown.

Unlike Clarke and Goldschmidt the Russian school of geochemists make extensive use of the ideas of geochemistry for solving practical problems.



Our geochemists are trying to follow M. Lomonosov and to employ the "methods of mathematics, physics and chemistry" in analyzing surrounding nature: at the same time they make a deeper geochemical analysis of Mendeleyev's periodic system.

Academician Vladimir Vernadsky was one of the most outstanding students of organic and inorganic nature, the creator of new scientific trends and the father of Russian mineralogy and world geochemistry.

He studied at the physico-mathematical faculty of St. Petersburg University and was graduated from it in 1885. It was the time when D. Mendeleyev was at his heyday and played a prominent part in the life of the University.

Young Vernadsky was fascinated by Mendeleyev's new ideas and was one of his most enthusiastic chemistry students. He appreciated the value of experiment in exact knowledge.

Another person who exerted an enormous influence on V. Vernadsky in those remarkable years of struggle for science was V. Dokuchayev, a man of rare initiative and efficiency. At his lectures V. Vernadsky learned to understand the importance of exact knowledge and precise methods of research.

From Dokuchayev's classical work *Russian Chernozem* Vernadsky borrowed the profound idea of the soil as a special natural-historical body, and many of his thoughts in biogeochemistry spring from V. Dokuchayev's scientific ideas.

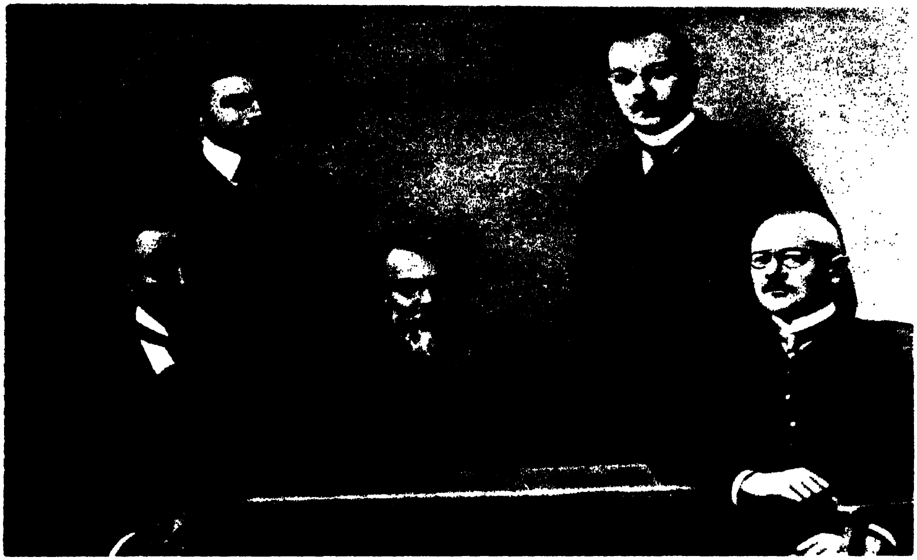
Vernadsky's long life (1863-1945) was one of persistent work and brilliant creative thought, a life which opened new fields in science and charted a new course in natural science in our country.

Vernadsky also played a very important part as a historian of science because he always laid the historical principle and the historical method at the basis of natural science.

He invariably wanted his pupils to elucidate the history of a problem. He used to say: "We naturalists must learn the profound historical methods of understanding the past fates of mankind from historians. Only by using these methods will we become historians of nature."

Twenty-one years of Vernadsky's life (1890-1911) were connected with Moscow University where he worked as professor of mineralogy and crystallography.

It will be observed that before Vernadsky the teaching of mineralogy



Academician V. Vernadsky among his young students at Moscow University. Photograph taken in 1911. V. Vernadsky is sitting in the centre; A. Fersman is standing on the right

at Moscow University was confined to a tedious description of the minerals. The collections were in disorder. Vernadsky not only put them in order, but also enriched them with his own exhibits collected during his numerous excursions and travels. He very frequently travelled in Russia and abroad and considered these excursions very important in the matter of training future scientists. V. Vernadsky radically reorganized the teaching of mineralogy replacing the dry descriptive science by a chemical mineralogy based on history and by teaching a separate course of crystallography. He organized the first scientific mineralogical circle which included all the mineralogists of Moscow. At the same time he obligated his co-workers and pupils to do experimental work in physico-chemical description of chemical compounds and minerals, which played a very big part in developing the school of mineralogy.

These were the sources of Russian chemical mineralogy and later of geochemistry, and the school of V. Vernadsky's pupils, the mineralogists-geochemists, thus came into being at Moscow University.

The first edition of his voluminous fundamental classical work *Experiment in Descriptive Mineralogy* made its appearance in 1906 as a result of broadly conceived and regular investigations of numerous deposits of various minerals (the work was completed in 1918).

In 1909 Vladimir Vernadsky was elected Member of the Academy of Sciences. In 191[illegible] he moved to Petersburg and began a new stage in his life; whereas the first 20 years had been spent on developing a new scientific school, the subsequent years (the Petersburg period) were devoted to organizing new scientific work.

This change was no easy matter. Vernadsky missed Moscow a great deal. He gave up teaching and tried to devote himself fully to research work concentrating it in the walls of the Academy of Sciences. He entered the Academy at the time it was headed by A. Karpinsky, the Russian scientist who had laid the basis for studying the geological structure of the Russian Plain.

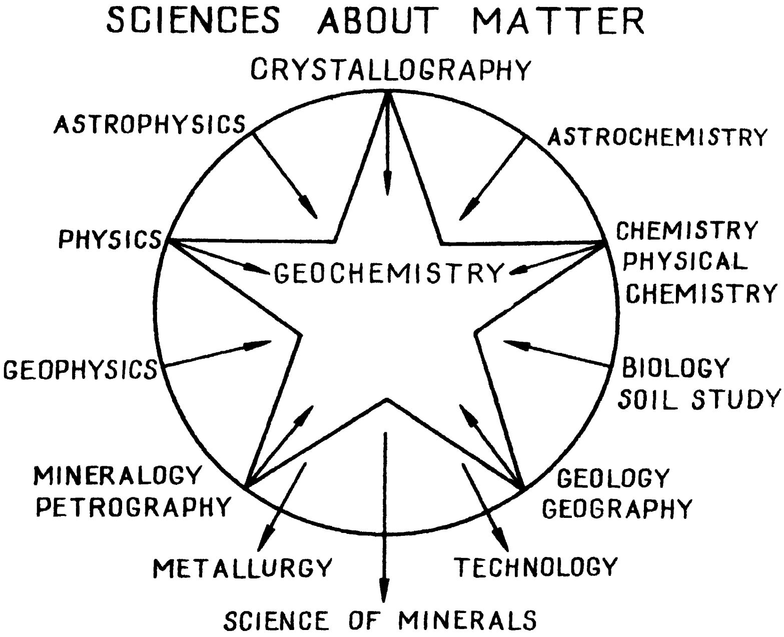
Vernadsky conducted extensive spectroscopic investigations of the distribution of rare and dispersed chemical elements in the Russian rocks and minerals and was the first to raise the question of the necessity of a wide and regular study of radioactive phenomena on the territory of Russia.

In 1922 he founded a radium institute in association with Academician V. Khlopin; an accurate methodology for estimating the age of rocks by lead and helium was developed at the institute.

The following words uttered by Vernadsky sound as if they were said today: "We are approaching a great revolution in the life of man not to be compared with anything ever experienced before. It will not be long before man lays his hands on atomic energy, a source of power that will enable him to organize his life at his will. This may come about in the nearest future or it may take another 100 years. It is clear, however, that it will. But will man be able to utilize this power for his own good rather than for self-destruction? Has man sufficiently matured to make use of the force that science must inevitably provide him with? The scientists must not shut their eyes to the possible consequences of their scientific work and of the scientific process. They must feel responsible for the effects of their discoveries.

They must tie their work in with a better organization of all of humanity" (*Essays and Speeches*, 1922).

As a result he developed a new, radiogeological trend in science, while the work on radium was put on a broad scientific basis. Somewhat later he began publishing his voluminous *History of the Minerals in the Earth's Crust* (1923-36). This very valuable scientific work was, unfortunately, unfinished. At the same time he integrated his remarkable geochemical ideas and published his book entitled *Essays on Geochemistry* (1927-34).



Geochemistry among kindred sciences

In his work Vernadsky showed on a number of separate elements how important it was to abandon the old point of view in studying minerals as complex molecules and to begin investigating the atom and its paths of migrations in the earth and in the cosmos.

In 1928 he founded a biogeochemical institute at the Academy of Sciences and became the father of a new branch of geochemistry—biogeochemistry. This science studies the chemical composition of living organisms and the participation of living substance and the products of its decomposition in the processes of migration, distribution, dispersion and accumulation of chemical elements in the earth's crust.

In 1935 the Academy of Sciences was transferred to Moscow. During the second period of his Moscow activities (1935-45) Vernadsky devoted most of his attention to his work in the biogeochemical laboratory; he personally investigated the biochemical role of carbon, aluminium and titanium and pointed out the necessity for drawing up a geochemical map of the biosphere.

The word "geochemistry" was uttered more than 100 years ago, but real geochemical science was born only in the last 30 years, in the years of the new stormy quests; Soviet science has played an especially important part in this; it boldly forges ahead, develops new branches of knowledge and in its aspirations and achievements combines theory with practice.

HOW THE CHEMICAL ELEMENTS AND MINERALS WERE NAMED

This question should be of interest to all of us. It is not so easy to remember the hundreds and thousands of the different names of elements, minerals and rocks. But if we grasp the meaning of each name they may be easier to remember.

Some of the readers may have come across my little book *Recollections about a Stone* and may remember the facetious story in it about the way new minerals and new stations of the Kirov Railway were named. It ridiculed especially the old railwaymen who had given the name of Africanda to a station only because they had arrived there on a day when it was as hot as it is in Africa.

Another station was named Titan though not a trace of titanium ores had been found anywhere around.

We must confess, however, that not only our old railwaymen acted this way; chemists and mineralogists did the same when they discovered anything new: each of them named things at will and all we can do now is remember these names as they are. In chemistry it is simple enough; there are only about 100 chemical elements for which names had to be thought of. It is much harder in mineralogy where close to 2,000 minerals are already known and where from 20 to 30 new ones are discovered every year.

Let us first try and make out the names of the chemical elements on which the science of chemistry rests; the chemical symbols were made up of the first letters of these names in Latin: Fe (*ferrum*—iron), As (*arsenicum*—arsenic), etc.

Chemists and geochemists most frequently and most willingly named the newly discovered elements after the country or city where the discovery was made or where a compound of the given substance was first found.

We can, therefore, easily understand such names as europium, germanium, gallium (from the ancient name of France—Gallia), and scandium (Scandinavia); these names can be easily remembered; it is much harder to remember the names in which ancient designations of cities or countries were used. It is sometimes very difficult to guess the origins of these names.

Ru
My name is Ruthenium and I was born in Russia

Thus, when a new element was discovered in Copenhagen in 1924 it was given the name of hafnium, the old and unknown name of the Danish capital. Lutecium was similarly given the old name of Paris. Thulium is the old Scandinavian name of Sweden and Norway.

The metal ruthenium, which was found in Kazan by chemist R. Klauss, was named in honour of Russia, but, unfortunately, it scarcely occurs even to many competent chemists that "ruthenium" stands for "Russian."

A curious thing happened to one of the feldspar quarries near Stockholm in Sweden; the Ytterbi pegmatite vein yielded a large number of new elements, and the names "ytterbium," "yttrium," "erbium" and "terbium" resulted from the different versions of this name.

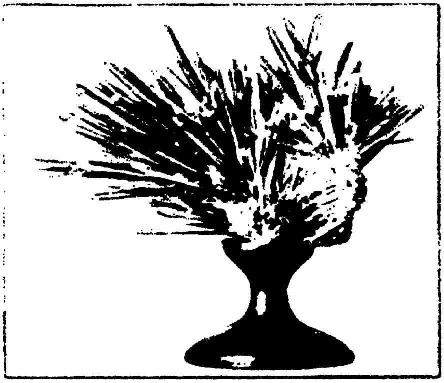
Many chemical elements were given their names on the basis of their physical and chemical properties. This would seem more rational, but these names are intelligible to, and easily remembered by, those who have a good knowledge of old Greek and Latin.

Since a series of chemical elements were discovered on the basis of their colour lines in the spectroscope these elements were given their names according to the colour of these lines: indium by its blue line, cesium by its azure-blue, rubidium by its red and thallium by its green line.

Other elements were named after the colours of their salts; for example, chromium—from the Greek word meaning "colour"—was so named because of the bright colouring of chromium salts, while iridium was given its name because of the iridescent colours of the salts of this metal.

Very many chemists, who were keen on astronomy, named certain elements after planets or stars. Such are the names of uranium, paladium, cerium, tellurium, selenium and helium. Only the last name has a deeper meaning because helium (*helios*—sun) was first discovered in the sun.

A still greater number of names were given in honour of the gods and goddesses of antiquity. Vanadium was, thus, named in honour of a goddess, while cobalt and nickel, the harmful fellow-travellers of silver ores, were named after the wicked gnomes who were supposed to live in the Saxon mines.

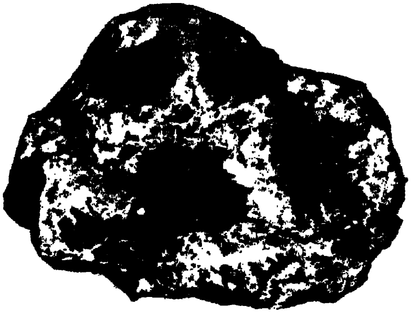

Stibnite

The names of tantalum, niobium, titanium and thorium were taken without any particular reasons from ancient mythology. Antimony was known in the Middle Ages by the name of antimuan, which most probably stems from the Greek word meaning "flowers," since the crystals of stibnite arrange themselves in bunches resembling the flowers of the compositae. According to another version antimuan is derived from *antimonk* allegedly because antimony leads recluse monks into temptation.

Much less attention was devoted to the names of world-famous scientists. The mineral gadolinite was named in honour of the Russian professor A. Gadolin, and the element was named gadolinium after the mineral.

The name "samarium" comes from the mineral in which it was discovered; samarskite was first found in the Ilmen Mountains in the Urals and was named in honour of Colonel Samarsky.

Ruthenium, gadolinium and samarium are three elements whose names are of a purely Russian origin.


Samarskite (black)

In addition to all these complicated and at times unreasonable names, however, there are about 30 chemical elements which in the roots of their names have various ancient Arabic, Indian or Latin words.

The origin of the words *aurum* (gold), *plumbum* (lead), *arsenicum* (arsenic), etc., is responsible for many arguments. Finally, there are several new transuranium elements; neptunium (Np) 93, and plutonium (Pu) 94 were named after planets; americium (Am) 95 stems from the word America, and curium (Cm) 96 was named in honour of Marie Curie, etc.

See what chaos and disorder! Greek, Arabic, Indian, Persian, Latin and Slavonic roots, gods, goddesses, stars, planets, cities, countries and surnames frequently without any rhyme or reason.

True, there were attempts to put some order into the system of names of elements, but there are so few of them that it really does not pay. It is quite a different question with the names of minerals.

Here the geochemist and mineralogist must radically alter their practice because more than 25 new minerals must be named every year and it is, certainly, unreasonable to name such compounds as laurite after the chemist's bride Laura and to give to a series of minerals names of princes and counts out of loyalty to these people who never had anything to do with minerals, as was the case, for instance, with uvarovite.

Finally, some names are so incongruous that we can hardly pronounce them, for example, ampangabeite, named after the place where it was found in Madagascar. The names of the minerals form a most interesting page in the history of mineralogy and chemistry. The origin of the names of a number of minerals is still unknown, and many of them have their roots in ancient India, Egypt or Persia. Persia has given us turquoise and emerald (smaragd), ancient Greece—topaz and garnet, and India—rubies, sapphire and tourmaline.

Topaz from Murzinka deposits (East Urals)

Crystals of limespar

Many minerals were named after their locations. Thus, such names as ilmenite (Ilmen Mountains in the South Urals), baikalite (Lake Baikal) and murmanite (Murmansk Region) are very well known and intelligible to us Soviet people. But the most interesting name to us is connected with Moscow; it is moscovite or muscovite, the famous potash mica which plays so important a part in the electrical industry. Very many names were given in honour of well-known scientists, prominent chemists and mineralogists. We shall mention scheelite, so called in honour of the well-known Swedish chemist Scheele, goethite—in honour of the poet and mineralogist W. Goethe, and the familiar mendelevite and vernadskite.

It must be admitted that the names given to minerals on the basis of their colour are very suitable, but one must know Latin or Greek to understand these names. These include, for example, aquamarine (colour of sea-water), auripigment (colouring of gold), leucite (from the Greek word *leucos*—white), cryolite (from the Greek word meaning "ice") and celestite (from the Latin word meaning "sky").

Very many names stem from the physical and chemical properties of the mineral. Thus, silver-like minerals are called glances, copper- or bronze-like minerals are known as pyrites, minerals which have a capacity for splitting in several directions are called spars, while minerals that contain metal which it is hard to guess by the deceptive exterior are known as blendes.

The diamond received its name from the Greek word *adamas*, i.e., invulnerable, invincible, adamantine. It must, finally, be admitted, that many minerals were rightly named after the chemical elements

Oriental precious stone merchant. 17th-century engraving

which formed their main constituent. These include, for instance, phosphorite, calcite, wolframite, molybdenite, etc.

There are some names, however, that evoke a special interest. Some of them are connected with legends; the meaning of others is concealed in the entrails of the alchemists' laboratories. Thus, asbestos received its name from the Greek word meaning "unburnable." Nephrite owes its name to the medieval error that it allegedly cured kidney disease. Phenacite—"deceptive" was so named because its beautiful wine-red colour fades when exposed for a few hours to the sun.

Apatite, or "deceiver," was given this name because it is hard to distinguish from other minerals; finally, amethyst has borne its name since the Middle Ages when the mysterious property of serving as a protection against drunkenness was ascribed to it.

This brief description shows what a complicated business the naming of minerals is.

Isn't it at all possible to bring order into this matter? Isn't it possible to organize an international commission which might sanction the names of new minerals and which might see to it that they correspond to the properties of the minerals, that they be easy to remember, that the very names form some sort of a system and that they classify the hundreds and thousands of mineral species?

We hope that, as the chemical and geochemical sciences continue to develop and prosper, our little proposal will be given consideration so that the school child and the student may no longer be tormented with long and hard-to-remember names, and that the names given to the minerals be closely related to the characteristic properties of the stone, the plant and the animal in order that they may be easily committed to memory.

CHEMISTRY AND GEOCHEMISTRY IN OUR TIME

We are living at a time of grand achievements in physics and chemistry.

The old metal — iron — is beginning to be replaced by others or be combined with a number of rare metallic substances.

Complex compounds of silicon in glass, porcelain, brick, concrete and slags are beginning to substitute for the old iron structures.

Organic chemistry — chemistry of carbon — has made tremendous headway of late, and large factories have already taken the place of the enormous fields of indigo and rubber plantations.

These factories produce synthetic rubber and paints from products of coal distillation, which already now not only replace the natural vegetable dyes, but also yield a much wider scale of colours.

As a matter of fact, the world is now using ever more chemistry in science, economy and life. Chemistry is penetrating into every little detail of our day-to-day life, into every particular of the most complex apparatus of industrial production.

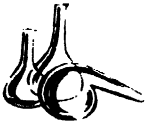
And it stands to reason that in addition to the more extensive uses of chemistry we are extending our studies of the natural resources and the mineral raw materials because our economy and industry need enormous quantities of them.

Geochemistry is so closely related to chemistry that it is frequently hard to draw a line between these two sciences.

Organization of special research institutes and laboratories now forms the basis of the development of the chemical industry, and we gratefully recall the words of the famous French biologist Pasteur, who as early as 1860 said:

"I beseech you to devote more attention to the sacred asylums known as laboratories. Insist that there be more of them and that they be better equipped. These are the temples of our future, of our wealth and of our welfare."

Since the Great October Socialist Revolution an extensive network of research institutes working in the field of chemistry has been organized in the Soviet Union.



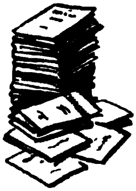
Special chemical institutes have been set up. Many of these have also dealt with geochemical problems. Some of them have successfully developed technological schemes for utilizing aluminium ores, others have brilliantly solved the problems of using boron and its carbides, still others have extensively studied the salts found in the Soviet Land's deposits and a number of elements rare earths, platinum, gold, niobium, tantalum, nickel, etc.

The Geochemical Institute of the U.S.S.R. Academy of Sciences, founded for the elaboration of more special problems, has conducted a number of investigations; the work of this institute has laid the basis for the collective geochemical thought in the country.

The Mendeleyev Society, which continues the glorious traditions of the Russian Physico-Chemical Society, is extensively propagating chemical ideas; the Mendeleyev Society unites in its institutions and branches several thousand people.

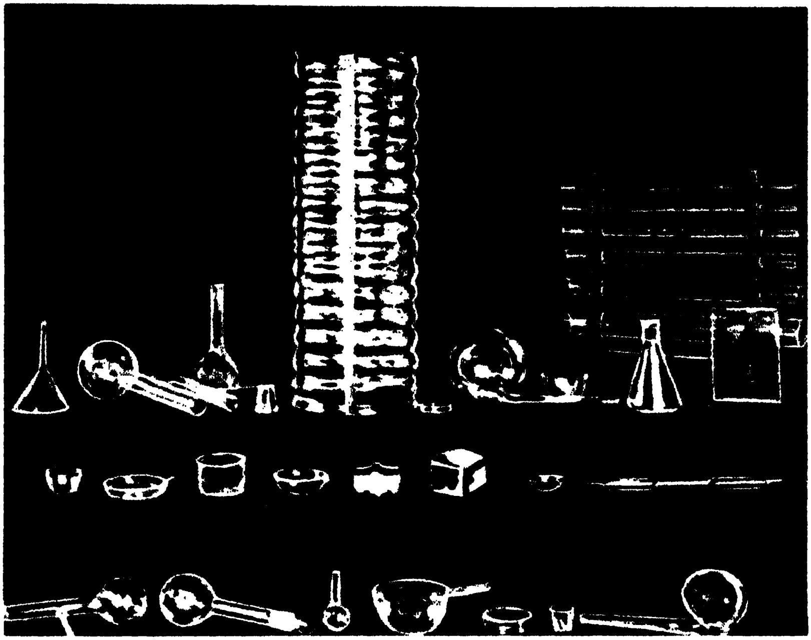
Mention must also be made here of the All-Union Mineralogical Society founded in Petersburg in 1817 and still vigorously elaborating problems of mineralogy and petrography.

Geochemistry has won wide public recognition, and geochemical thought has begun to penetrate into all scientific studies of minerals.



A Soviet chemist has calculated that more than a million scientific papers dealing with chemistry have been published in periodicals in the last 30 years; close to 80,000 of these have been published in the last few years alone. In order to follow up this enormous literature, there are special journals which review all articles published throughout the world in more than 30 languages, and in nearly 3,000 chemical journals.

However, when we speak of the numerous investigations conducted in recent years, we must not forget that an overwhelming part of these deals with carbon compounds, that a very large number of them is



Chemical utensils made of quartz

related to purely technical problems and that only about two per cent of them are closer to the problems of geochemistry, to the problems of studying the substance in the earth's crust, its abundance, migrations, structure, combination and formation into ores of the grades employed in industry.

The expansion of scientific work in the research institutes and societies, and the development of publishing has enabled the chemical sciences to pose ever deeper and broader problems. Though 200 years have already passed since Lomonosov's death, we can still use the first paragraph of his foreword to the lecture on physical chemistry delivered by him in 1751 as the basic motto in our chemical work: "The study of chemistry may pursue a double aim; one of these is the perfection of the natural sciences, the other—multiplication of the good things of life."

Roentgenometric laboratory

As a matter of fact, chemistry and physics have not only perfected the natural sciences, but have also opened before us the mysteries of nature hidden from our eyes; science and engineering have been able to reveal to us the multiformity of atoms, of which the world is composed.

Owing to the achievements of the chemical sciences, modern industry now produces about 50,000 compounds of different elements, while the number of organic compounds developed and studied in laboratories runs into one million. There is no end to the compounds laboratories can still produce.

How grand these figures are compared with the 2,500 compounds we know in nature! And yet precisely nature was our first teacher of the chemical sciences. Our industry is based on mineral raw materials. The direction of the work in chemical laboratories depends on them; both the structure of substance and the course of chemical reactions have been studied on natural materials.

That is why it took geochemistry to build a bridge between the chemical and the geological sciences. By studying the properties and reserves of the world's mineral raw materials, geochemistry has not only revealed the structure of crystals in association with crystallography, but also charted the course for the development of industry.

Thus, the sciences formed a continuous chain from geology to geochemistry, from geochemistry to the chemical sciences and to physics. And the final aim of all these sciences has been not only the perfection of the natural sciences, but, as Lomonosov said, also the multiplication of the good things of life which man has always striven to produce.

The creation of new valuable substances and the conquest of raw materials for the national economy have been the greatest and basic stimuli in our days. Technology has closely joined geochemistry, studying the properties of ores and salts, finding out the distribution of rare elements in them and seeking for ways of the best and fullest possible utilization of the entrails of our earth.

The combination of chemistry, geochemistry and technology had made modern development of the chemical industry possible.

We shall not dwell any longer on what benefits the development of chemistry and the chemical sciences has brought and will yet bring mankind; we spoke about it in the chapter on the history of the atom in the history of mankind; we shall come back to this in the following chapter, when we try to paint a picture of the future of our sciences and of their accomplishments.

We are now interested in something else, namely, what the modern investigator in chemistry, the one who advances science, creates scientific laboratories and thus conquers the surrounding world, should be like.

In the past chemists took individual substances (elements) from rock and studied them in their laboratories and offices outside time and space, outside their relations to nature.

Today man pictures the world as a complex system in which all the individual parts are closely interrelated, where various forces collide, combine and struggle with each other as in an enormous laboratory, where only as a result of this struggle of individual atoms and of electric and magnetic fields substances are created in one place and destroyed in another.

The world is a vast laboratory, where all things are connected with each other like individual gears in a machine. And the modern chemist who has come to replace the old laboratory recluse sees each atom in a new light by closely linking its fate with the fates of the universe. This is why chemistry is now coming so close to geochemistry.

Today a scientist has new objectives: it is not enough for him to describe individual phenomena, separate facts of surrounding nature or observe the results of some experiments in his laboratory. He is studying substance, i.e., he must understand how and why it came to be and what will become of it.

Extensive reasoning of a philosopher about the laws of nature will no longer do for him; he must study their eternal course in the phenomena around us; he must discover the complex relations between the individual phenomena.

An investigator must not dispassionately sketch or photograph individual natural phenomena, he must strive to conquer and subordinate them to his will. The new investigator must not be an artisan in his laboratory, but a creator of new ideas born in the struggle against nature for the conquest of the world.

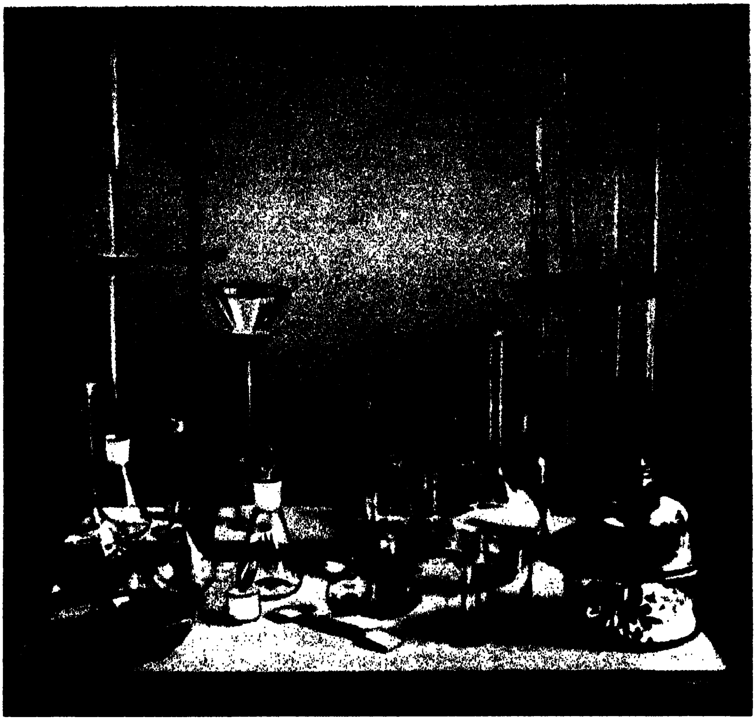
Now the chemist, like the astronomer, must foresee things: his experience is not a series of separate accidental reactions in the test-tubes of his laboratory: his experience is born as the fruit of creative thought, scientific fantasy, and profound quests. The modern chemist must understand that scientific victory is not won all at once, that it grows gradually by long verification and nourishing of separate ideas, that it is achieved only as a result of continuous quests over a period sometimes of generations of scientists, that it is not infrequently the last drop that overfills the cup.

That is why discoveries in modern science are frequently made at the same time in different countries, and the greatest ideas for conquering the world that surrounds us occur almost simultaneously to many scientists.

Success in work depends on the ability to observe and collect facts. In the field of geochemistry this is one of the most important problems. We must confess that in their fascination with a theory and sometimes with logically harmonious generalizations investigators cease to observe and do not see that which is unclear, which does not agree with their former conceptions and which is the key to new discoveries. The ability to sense what is new and to reject in good time the old, customary hypotheses, is a quality indispensable to a real scientist.

What if many people think that it is an accident that is responsible for a discovery, that Roentgen accidentally noticed the action of X-rays on a luminescent screen, and that the investigator has accidentally discovered vast accumulations of manganese carbonate in far-off Siberia! This accident, however, is always nothing but the subtlest ability to sense the new.

To think of the number of investigators who for a period of many years passed near white rocks considering them simple limestones, tested them with hydrochloric acid, convinced themselves that they



Chemical utensils made of glass

hissed and went away! But they should have noticed that in some places in fissures and on the surface, these white rocks were covered by a black crust, that this crust was not something alien and that it seemed to be born of the white stone. It is thus the largest manganese deposits were discovered in Siberia. And it was no accident that discovered them; it was profound and consistent observation and the knowledge of facts that led to this discovery.

There is one more aspect in this ability to observe which was so remarkably noticed by Lomonosov. He said that observation should give rise to a theory and that the theory should correct the observation: he was perfectly right, because every subtle and skillful observation is born of a theory, and each theory makes sense only when it is based on an enormous number of accurately observed and precisely described facts.

What must a real geochemist be like, then?

He must be purposeful; he must pursue a definite aim unwaveringly; he must be a thoughtful observer; he must have a lively young imagination; he must have the youth of mind and soul which are not determined by age, but by the sensitivity of his very nature. He must possess enormous patience, mettle and industry and, above all, the ability to see a thing through to the end.

It is not without reason that Benjamin Franklin, one of the most prominent scientists, said that genius was the capacity for endless work.

But a scientist must at the same time have common sense and scientific fantasy. He must have faith in his work and in his thought; he must be convinced of the correctness of his thought, be bold in defending it; he must be enthusiastic about his work and love it. Enthusiasm in work is one of the most important requisites for victory. The artisans in science have never made a single important discovery.

Without enthusiasm it is impossible to conquer the world, and this enthusiasm is born not so much of the fascination of creativeness itself, as of the understanding of the role and of the responsible task which man discharges in his creative endeavours.

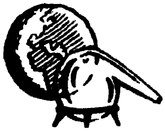
Fascination with the idea of raising the living standards, fervent desire to subdue life's sinister forces, the striving to build a new and better world and to give it new resources and opportunities for mastering all the accumulated knowledge is the aim of life of the new man in the new, free country.

And it is only thus that the world can be conquered.

In his autobiography Charles Darwin said: "... my success as a man of science, whatever this may have amounted to, has been determined, as far as I can judge, by complex and diversified mental qualities and conditions. Of these, the most important have been - the love of science - unbounded patience in long reflecting over any subject - industry in observing and collecting facts - and a fair share of invention as well as of common-sense."

These are the traits we now want to see in the geochemist. They are not born in man all at once; they are trained by persistent work; they do not come into the world with the individual, but are educated and developed in creative life.

The greatest conquests of chemical thought pass before our eyes and thousands of examples show us how nature is vanquished by the enthusiasts of science.



FANTASTIC TRIP THROUGH MENDELEYEV'S PERIODIC TABLE

"What do you propose to exhibit as the most remarkable achievement of Russian science?" I was asked by one of the organizers of the All-Union Exhibition of Science and Engineering, to be held in Moscow a few years later.

"We must exhibit something the like of which cannot be found anywhere else in the world and which would show the glory and power of Soviet science in its gradual development since Lomonosov to our time."

We were carried away by this idea; we talked to chemists and geologists and submitted our proposal. At first it appeared too grand and fantastic, but later our critics agreed with us; the idea fascinated them and they began to develop it together with us.

* * *

Imagine a building in the form of an enormous cone or pyramid of chromium-plated steel 20 to 25 metres high, approximately like our five- or six-storey houses. A grand spiral squared into boxes runs around the cone; the boxes are arranged as in Mendeleyev's system to form long series and vertical groups. Each box is a small room and is occupied by an individual element. Thousands of spectators descend the spiral examining in each box the fate of an individual element in the manner they would examine a beast in a cage of the Zoo.

To rise to the top of the enormous cone of Mendeleyev's Periodic Table you enter the "elementarium" on the ground. At first almost complete darkness envelops you and only separate red tongues begin, as it were, to lick your feet and you are gradually surrounded by a seething mass of a boiling fiery melt. You find yourself in the glazed cabin of a large lift. The molten ocean of the earth's interior is all around you. The cabin slowly rises amid the tongues of fire and the streams of molten masses.

The first points of hardened crystallized substances of the magma make their appearances. They are still floating in the melt, are rushing about in masses and are gradually accumulated in separate sections in the form of glittering sparklets, of hardening rocks.

Now the cabin has already touched this cooled magma of the interior on the right. You see the dark still red-hot basic rock rich in magnesium and iron. The black spots of chromite merge into bands of chromium ores and amid them you see the crystals of platinum and osmiridium, these first metals of the earth's interior, sparkling like stars.

The cabin is gradually moving past such a dark-green boulder. In its long history this boulder broke up many times and was again soldered by some fiery liquid melt. Shiny little crystals of transparent stone glitter amid the dark green crystals. These are crystals of diamonds which were brought out into similar diamond-bearing pipes in South Africa.

You get the impression the cabin is rising faster and faster. You leave the dark green rocks of iron and magnesium below. Here continuous masses of grey and brown rocks—diorites, syenites and gabbros—make their appearance; white veins gleam here and there among them. The cabin suddenly takes a sharp turn to the right, and runs into molten granite saturated with gases, vapours and rare metals: it is all impregnated with a hot fog. You can hardly make out the individual solid crystals in the chaos of the molten granite. Oh, the temperature here has already reached 800° C.!

Hot vapours break out to the surface in stormy streams and with explosions. Here you see a hardening mass of granite still pierced by molten remains of the same granite. These are the famous pegmatites in which the beautiful crystals of precious stones are born; these include smoky morions, green beryls, blue topazes, rock crystals and amethysts.

And through the fog of the cooling vapours the cabin goes past remarkable pictures of pegmatite cavities. Here you see large smoky quartzes more than a metre in diametre and next to them already formed crystals of feldspar. Plates of mica grow slowly on their surface and above them gleam smoky quartzes. Marvellous rock crystals seem to pierce the cavity with a transparent forest of lances.

The cabin rises higher. Lilac brushes of amethysts envelop it on all sides. It breaks out of the pegmatite vein and now new pictures attract your attention—veins of various thickness branch off now to the left and now to the right; now you see continuous trunks of white minerals and glittering sulphides and now thin veins hardly visible to the eye and closely resembling branches of a tree. Entire sections of the granite rock are impregnated with brown crystals of tinstone and yellow-pink masses of scheelite. The electric light in the cabin is turned off. You find yourself in darkness. The levers of a powerful machine are turned and it begins to emit invisible ultra-violet rays; the dark walls are now illumined by new lights; now with the delicate green of the scheelite crystals and now with the yellow of the calcite grains. The minerals sparkle, play and glitter with the phosphoric light and amid them you see dark spots of the compounds of heavy metals.

Then the light goes on again. The cabin leaves the contact zones of granites and moves along one of the powerful trunks rising from the granite massif. The cabin slows down and you rise along a real lode. The cabin now runs into a continuous quartz body. Black sharp crystals of tungsten ores pierce the quartzes and several hundred metres further up the first glittering sparklets of sulphides, these silvery-yellow crystals of compounds of iron and sulphur make their appearance. These are followed by blinding bright-yellow sparkles.

"Look, there is gold!" one of you exclaims. Thin veins pierce snow-white quartzes. The cabin rises several hundred metres more. Instead of the gold you now see the glittering steel-grey crystals of galena, then the zinc-blende which sparkles like diamond, various sulphide ores, shot with the colours of all metals, the ores of lead, silver, cobalt and nickel. Higher up the veins grow lighter. The cabin now moves through soft limespar pierced by needles of silvery stibnite and sometimes by blood-red crystals of cinnabar. Farther on you see the continuous yellow and red masses of arsenic compounds. The cabin makes its way with increasing ease; hot vapours and then hot solutions have long since replaced the hot melts.

The cabin is now showered by hot mineral springs. They seethe and boil with the bubbles of carbon dioxide and make their way through the sedimentary rocks which shackle the earth's crust. You see them corroding the walls of limestones, depositing zinc and lead ores in them. The hot mineral springs carry the cabin higher and higher and beautiful lime stalactites hang from the walls around you; these are now stalactites of brown aragonite (Carlsbad stone) and now beautiful sediments of particoloured marble onyx.

But the paths of the hot springs branch out and thin streams break through to the earth's surface, thus creating geysers and mineral waters. Our cabin is now moving through sedimentary rocks; it is cutting through layers of coal and running into strata of Permian salts; pictures of the distant past of the earth's surface open themselves before your eyes. Now heavy liquid drops fall and obscure the glass walls of the cabin. This is oil and various bitumens in the sands of the sedimentary rocks. The cabin cuts through separate horizons.

Underground waters shower the walls of the cabin again; it is now passing through a continuous wall of hard sandstones; soft limestones and argillaceous slates surround the cabin thus showing you the variegated pattern of the past fates of the earth. The cabin comes ever closer to the surface of the earth. One more rush in its rapid motion and the cabin stops.

A bright flame rises to meet you and snow-white clouds of water vapours of magic form cover the sky.

You have come to the top of Mendeleyev's Periodic Table. Before your very eyes hydrogen is burning into clouds of water vapours.

* * *

You are on the top platform of Mendeleyev's table. A steep spiral leads you gradually downwards. You hold on to the banister of chromium-plated steel and begin your descent.

Here is the first box. Inscribed on it in large letters is the word "Helium." It is a rare noble gas, first discovered in the sun, a gas that impregnates the entire earth, the stones, the waters and the air. Helium is an omnipresent gas and we search for it in order to fill our dirigibles. Here in this small room devoted to helium you see its entire history from the bright green lines of the solar corona, to the black unassuming cleveite, the stone from the Scandinavian veins from which helium, the gas of the sun, can be extracted with a pump.

You lean carefully over the banister and see five more boxes under that of helium. The names of other noble gases—neon, argon, krypton, xenon and radon, the radium emanation—are inscribed in them in fiery letters.

The spectral lines of the noble gases are suddenly turned on and everything is illumined by bright colours. The orange and red shades of neon are followed by the bluish tints of argon. Long trembling bands of bluish heavy gases complete the picture, which is very familiar to us by the luminescent shop advertisements in the city.

A light goes on again and you see the box of lithium. It is the lightest alkali metal. You see its entire history all the way to the aircraft of the future. You lean over again and again you see the luminous letters of its analogues: the yellow colour of sodium, the violet of potassium, the red shades of the signs indicating rubidium and the blue colour of cesium.

Thus, gradually, step by step, element after element you make the rounds of the great Mendeleyev Periodic Table down the spiral, and all we have told you about in the pages of this book, the entire history of the individual chemical elements is shown here in vivid, real specimens, in the very history of each element rather than in separate words or pictures.

Can you think of anything more fabulous than the box of carbon, the basis of life and of the entire world? The entire history of the development of living substance passes here before your very eyes as well as the entire history of the death of this substance when life buried in the interior of the earth is transformed into coal and living protoplasm into liquid oil. And in the remarkable picture of the complex world of the hundreds of thousands of chemical compounds of carbon your attention is attracted by its beginning and its end.

Here is an enormous diamond crystal. No, this is not the famous "Cullinan" cut into pieces for the English king: it is the "Orlov." It is set in a golden cane, the sceptre of the Russian tsars.

At the end of the same room you come upon a layer of coal. A miner's pick cuts into the coal and pieces of this plain-looking stone are transported by a long conveyer to the surface. This is the industry's staff of life.

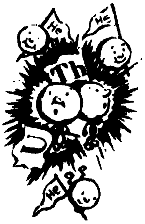
Then you go two more turns down the spiral and before you is a room with bright colours: yellow, green and red stones sparkle iridescently. Here you have the mines of Central Africa and there the dark caves of Asia. The film turns slowly, presents pictures of individual mines and shows the origin of metals. This is vanadium, named after the legendary old Slavic goddess, because of the fabulous strength it imparts to iron and steel by making them hard and durable, viscous, resilient and indestructible—the qualities so essential to the automobile axle. In the same room you see axles made of vanadium steel after millions of kilometres of service; near-by you observe broken axles made of ordinary steel which had not lasted even 10,000 kilometres.

You make a few more turns down the spiral. Pictures follow each other. Now you see iron —the basis of the world and of the iron industry, now omnipresent iodine fills the space with its atom, now strontium glittering in the red flares, and now the shiny metal gallium which melts in the hands of man.

Oh, how beautiful the room of gold is. It glitters with thousands of lights. Here is gold in white quartz veins and here is the silvery, almost green gold of the Transbaikal mines; there you observe a golden streamlet in a small model of the Leninogorsk concentration mill in the Altai; here you see an iridescent gold solution, and here is finally the gold in the history of man and his culture. It is the metal of wealth and crime, the metal of war, plunder and violence. The vaults of the state banks with gold bullion pass before your eyes in vivid colours: you see depressing pictures of slave labour in the famous Witwatersrand mines and of the bankers who shape the fates of stock companies and the value of currency.

Only one more step and you are in a room of another metal—liquid mercury. As at the famous Paris exhibition of 1937 there is a fountain in the middle of the room, but it is one of liquid silver mercury rather than of water. In the right corner you see a small steam engine beating time with its pistons and working on mercury gas, while on the left you observe the entire history of this volatile metal, its dispersion in the earth's crust, the blood-red drops of cinnabar in the sandstones of Donets Basin and the liquid drops of mercury in the Spanish mines.

But you go on. Beyond the boxes of lead and bismuth you run into some incomprehensible picture. The elements and the boxes



are all mixed up. You no longer find any clarity or distinctness in the separate squares. You have entered a sphere of special atoms of the Mendeleyev system. You find no more durability or stability in the familiar metals. Something vague and new appears before you; but then the fog lifts and you see a fabulous picture.

The atoms of uranium and thorium do not stay in their places. They emit rays of some kind and give rise to the globular atoms of helium. Our atoms leave their habitual boxes. Here they jump into the square occupied by radium, shed a mysterious light, are transformed, as in a fairy-tale, into an invisible gas called radon, then run back again through Mendeleyev's Periodic Table and die before your very eyes in the box belonging to lead.

But here is another and more frightful picture that replaces the first one; some very rapidly flying atoms strike uranium, break it into pieces with a great noise and the atom of uranium breaks up emitting brilliant rays; somewhere high in our spiral you see it flash in the box of the rare earths and then it runs down the spiral again, stops in separate boxes of alien metals and gradually dies somewhere near platinum.

What has happened to our atoms? Haven't they violated our laws? Haven't they shaken our conviction that each atom is an invariable and constant natural brick, that nothing can change or transform it, that strontium will always remain strontium and an atom of zinc will always be an atom of zinc?

You are terribly disappointed. Despite all we have said, the atom proved unstable. You have entered some new world where the atom turns out to be inconstant, where it can be broken up, not destroyed but changed into another one.

And through the fog of the end of Mendeleyev's table, amid the glittering sparks of the flying atoms of helium and the X-rays you descend to the last steps of the spiral into unknown depths.

Now you are not descending into the interior of the earth, but into that of the burning stars shining in the sky. You are going to where the temperatures are measured by hundreds of millions of degrees, where the pressure cannot be expressed in any values of our atmospheres, where the atoms of Mendeleyev's Periodic Table sparkle and break up in furious chaos.

Does this mean, then, that all we have said is wrong? Is it at all possible that the alchemists were right when they wanted to change mercury to gold? Were they right in trying to create silver from arsenic and the "philosopher's stone"? Does it mean that the dreamers in science were right when they said as far back as 100 years ago that the atoms were changing into one another, that in the complex worlds inaccessible to us they were born from each other?

Mendeleyev's Periodic Table is not at all a dead table, merely made up of boxes. It is not only a picture of the present, but also one of the past and of the future; it is a picture of the mysterious processes of the universe in which atoms are transformed into one another. It is the picture of the struggle for existence that prevails in the world of atoms.

Mendeleyev's Periodic Table is a table of the history and the life of the universe. The atom itself is a piece of the universe, constantly changing its place in the complex series, groups and boxes of the table.

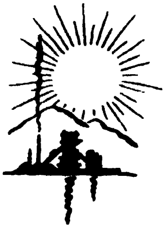
You have come to the most remarkable picture of the surrounding world.

FUTURE CONQUESTS

The stormy development of physics and chemistry in our days is only the threshold to the upsurge ever more clearly outlined in science, industry and economy. I believe the age of chemistry is coming; the age in which the genius of man will not only subjugate all the chemical elements, but will also awaken all the forces of the atom and utilize the immense reserves of energy concealed in each molecule, atom and electric particle. What if the following pages appear somewhat fantastic? The fantasy of today is very often transformed into the engineering of tomorrow.

Haven't Jules Verne's fantasies, which still fascinate us, been transformed into reality of today! We find an even greater scope of fantastic thought in our remarkable Russian scientist K. Tsiolkovsky and though only some thirty years have elapsed since his daring predictions, much of what he wrote then has already come true. We must, therefore, never fear scientific fantasy nor take it as something already existing; we must fight for it because fantasy is one of the methods of scientific work.

It was not without reason that Lenin said that fantasy was a quality of the highest value, that it was wrong to think that only poets needed it, that it was also necessary in mathematics because even the discovery of differential and integral calculus would have been impossible without fantasy.



Let us day-dream together about what our engineering will be like in the heyday of the chemical sciences.

In the first place, we will conquer the air, not only because planes and rockets will rise above the clouds, to an altitude of 50 to 100 kilometres and will fly at speeds exceeding the velocity of sound, but also because chemistry will master the air and will subordinate it to the power of man.

At large plants scattered throughout the world, helium will be extracted from the air, the air will be divided into oxygen and nitrogen and whole rivers of liquid oxygen will flow along artificially cooled pipes to large iron and steel mills, where the smelting of metal in blast-furnaces will become as simple as evaporation of water in a laboratory test-tube.

Similar plants will produce pure nitrogen transformed by powerful electric discharges into nitric acid. Life-giving nitrogen will be used as fertilizer for our fields on a very large scale and will double and treble their crops. Other pipes of the same installations of the air industry will carry streams of noble gases—liquid neon, krypton and xenon—to electric bulb-manufacturing plants.

But even more wonderful will be the victory over the layers of ozone which are formed under the influence of the ultra-violet rays of the sun at altitudes of hundreds of kilometres.

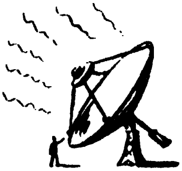
We know that these layers of ozone envelop the earth, as it were, by a continuous blanket, repelling radio waves and blocking the vivifying action of the ultra-violet rays.

Now, imagine this fantastic picture: enormous electrified columns of ammoniac compounds rise to a height of several hundred kilometres, i.e., to the famous ozone layer; the ozone breaks up, free windows are formed in it and through them the sun sends powerful streams of ultra-violet electromagnetic waves. In some places they destroy life, in others they impart a mighty force to it and serve as the source of new, life-giving energy.

But the conquest of the earth's interior seems even more fantastic. The ocean of magma boiling under our feet, the colossal amounts of heat concealed in the earth's entrails will all come within the reach of man.

By special mains running to a depth of 20 to 30 kilometres man will reach the layers heated to 500 and even 1,000° C.; he will utilize the heat of the earth's interior in his thermal stations; he will stop destroying forests and will cease uselessly burning coal which is so necessary for chemical processes; he will no longer spend oil for thermal installations.

Millions of calories will come to the earth's surface along these pipes. They will heat man's houses, factories and entire regions with their hot breath; they will melt the ice of the polar countries and will change the climate. Powerful refrigerators scattered throughout the deserts will transform them into flourishing oases.



But even this will not be enough for man. Man will not be content with the heat that will spread along the entire surface of the earth at his command and will remove the defects of the sun; he will bring to the surface the wealth concealed in the interior of the earth.

A new stage in the struggle for mastering the interior of the earth is already beginning in the Soviet Union in keeping with Mendeleyev's brilliant predictions.

In the earth's entrails inaccessible to mining man is now burning coal, and the products of combustion rise along pipes to the surface and are utilized by industry. This does not require either mines or the hard work of drillers, hewers and wheelers; automation, mechanization and remote control make it possible to utilize the coal reserves without going down into the mines.

Man is already extracting sulphur from deep underground deposits. Steam melts the sulphur in the interior of the earth, and its liquid streams pour out to the earth's surface; now if we pump steam heated to 500 or 600 C. into veins, into concentrations of heavy metal sulphides, the pipes made of a new stable material will bring us the sulphides of silver, lead and zinc, rather than mere sulphur.

Powerful layers of slates will be burnt in the interior of the earth and will yield useful gases to the surface. Salts will be dissolved and brought to the earth's surface in the form of solutions. Strong acid solutions will dissolve natural substances and give us salts for the electrolytic plants. All of our earth will be pierced by millions of steel pipes which will be extracting the substances required by man from various depths.

The victory over matter will be even more decisive when chemistry learns to collect the dispersed atoms of uranium and to utilize their energy.

Physicists now tell us that the world reserves of uranium energy are tremendous. By learning to split these disintegrating uranium atoms, man will build new engines which will serve flawlessly and will run for thousands of years on end forming a source of fabulous energy which will drive planes and ships alike.

The entire energy of the world will be placed at the service of man in new chemical installations. The rays of the sun falling so uselessly on the earth's surface will be caught up by enormous mirrors and will be transformed into heat. Solar kitchens in California and in the U.S.S.R., the first experiments in harnessing the energy of the sun, will become everyday practice.

The sources of the white and blue coal will be fully utilized; their energy will be caught by enormous stations along all sea coasts and river-banks. Man will become master of such enormous quantities of energy, that he will be able to perform real miracles.

And then man will master space, distance and time. Speeds of several thousands of kilometres per hour will become the usual thing; the distances between cities and other centres of habitation will be reduced to a minimum and will cease to divide people. New forms of life and a new social organization of the world will erase all earthly boundaries. The life of man will become the main objective of creative scientific endeavour. Man will learn to split atoms by fine methods; by means of radioactive rays and emanations from enormous cyclotrons man will be able to do anything he likes with the atoms; he will be able to break them up into separate pieces, transform the heavy atoms into light ones and, contrariwise, the light atoms into heavy ones.

By artificially producing various types of atoms, man will learn to utilize them. Man will be able to introduce the atoms which live only a second or a minute into the organism as new remedies to fight viruses and pathogenic bacteria. He will master the living cell by controlling it with the aid of the new chemistry. But for his powerful chemical processes he will also be able to utilize micro-organisms. Man already grows many of the useful bacteria he needs in gelatine contained in small test-tubes at institutes of microbiology.

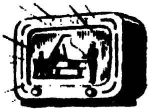
He will be able to produce them in immense quantities and to strew them over his fields. The bacteria will give the fields fertilizer—nitric acid—and by decomposing gypsum will extract sulphur. Man will transform bacteria into a vital force, into a powerful chemical agent and by using them, he will learn to extract the metals dispersed in the seas as it is done by the individual small acantharia who absorb strontium from marine solutions.

In his struggle for the earth's interior man will make use of the entire mass of rocks. There will be no waste products, no unused tailings. Everything will serve industry; all of Mendeleyev's Periodic Table will be utilized, and the most widespread elements—silicon and aluminium—will become the basis of life.

The name "super-rare" substances will no longer make any sense. These substances will form part of our everyday life. With their aid we shall develop TV screens and from our own rooms we shall be able to talk to distant audiences which we shall see on the screen with our own eyes. The rarest elements will serve for chemical reactions which at large chemical plants will be able to transform substances into products required for life.

Organic chemistry is becoming very important. Instead of the hundreds of thousands of carbon compounds known today, man will produce millions of new structures when he learns to use in his new installations low temperatures close to absolute zero, as well as temperatures of millions of degrees and pressures of hundreds of thousands of atmospheres.

Moscow State University on Lenin Hills



This will be a new chemistry of carbon. This will not only be the plastics from which we can manufacture anything from buttons to lightweight planes, not only synthetic rubber which is beginning successfully to replace natural rubber, not only the remarkable dyes which have rendered the plantations of indigo unnecessary; no, these will be entirely new substances, very close to the real organic molecule, to protoplasm, to protein. . . . These will be artificial nutritive substances which will do away with the superfluous complex chemical laboratories in the organisms of animals.

The new synthetic chemistry will also be able to utilize other elements in order to build the same complex compounds that organic chemistry has been able to construct from carbon, oxygen and hydrogen. I can already imagine the new molecules of silicon, germanium, boron and nitrogen in the remarkable compounds which the chemists have been able to produce in recent years by building the benzene ring not from carbon or hydrogen, but from two other elements of the earth—nitrogen and boron.

But for chemistry to master the world requires enormous scientific work: it needs powerful and numerous scientific institutes with perfect installations of high pressures and temperatures which must merge with the laboratories of factories.

And here in these new palaces of science victory shall be won by new and daring men armed with bold scientific fantasy and burning with a fire of new quests.

This is how I picture to myself the future in the light of today. But I took the colours for my picture from nature that surrounds us and from our knowledge. The pictures of the distant future will be even more majestic, but to paint them we now lack words, colours and images. . . .

The aim of our stormy quests is the happiness of humanity. The new life will be born as a result of victory over nature and over the inertness of man himself.

Man has a hard and stubborn struggle ahead of him, but the milestones of the future have already been placed and the objectives outlined. The struggle for nature, for the mastery of her forces, for the transformation of all that is useless into useful things will be one of the powerful levers in the creation of a new life.

END OF BOOK

We have come to the end of the book. You and I had to change into small wandering atoms in order to run through the complex paths of migrations of the elements, to look into the interior of the earth and even at the hot celestial bodies, to see the behaviour of various atoms in the universe and in the hands of man, and to find out what they do in industry and in agriculture.

The atoms travel a long way in their history and we do not know either its beginning or its end. The birth of the atoms and the beginning of their migrations on earth are still a mystery to us. Nor are their future fates, their fates in the complex future of our planet clear to us.

We only know that some atoms disappear beyond the limits of the earth and are dispersed in interstellar space where there is no more than one negligible atom per cubic metre and where only so small a part of space is occupied by them that it would have to be expressed by 10^{-30}.

We know that other atoms become dispersed in the earth's crust, in its soils, waters and oceans; still others slowly and gradually return to its interior, subject to the laws of gravity.

Some atoms are constant, invariable and as durable as pure, white ivory billiard balls; others are, on the contrary, as resilient as rubber balls, contract when colliding with each other and interlace in some complex structures surrounded by electric fields; still others completely disintegrate, nuclei and all, emitting energy and changing to strange gases whose life-span is precisely determined by the laws of disintegration and is measured by millions of years for some, years

Mineralogical Museum of the U.S.S.R. Academy of Sciences

for others and seconds or even negligible fractions of a second for still others.

The world around us is built of about 100 chemical elements, but what great multiformity they produce, how the features of these atoms vary and how their combinations differ!

Only now are we beginning to read in a new manner these remarkable pages in the history of the earth's chemical elements. Geochemistry has only just slightly opened the door into a new world of nature; hard and persistent work has only just started; the behaviour of each element in the earth's crust has only begun to be observed, but we must already keep a record of the behaviour of each atom, thoroughly examine its characteristic features and learn about its merits and defects; in a word, we must make so detailed and profound a study of

Record of the atom's behaviour

each atom as to be able to trace its fates, i.e., the history of the universe, from the separate facts.

Each link in this historical chain is dependent on the as yet unknown properties of the atom, while complex and profound laws govern its fates in the cosmos, on earth and in the hands of man alike.

But it is not out of mere curiosity that we want to trace the paths travelled by the atoms: it is not only because we want to know how they behave on earth; we must learn to control them in a manner required by man for his technical, economic and cultural progress.

Engels said we must study nature in order to reshape it. It is just this that constitutes the big and honourable problem of geochemists.

STUDY NATURE!

Yes, we must master the atoms completely and be able to do all we want with them, for example, to produce super-hard alloys, i.e., alloys harder than diamonds; but to do this we must know how the atoms arrange themselves in their complex structures.

We must learn to divine the properties of the compounds of metals; we want and must be able not only to try, but to know for sure.

We must obtain and produce the greatest possible quantities of such atoms as cesium and thallium which easily give off their outer electrons. With these we want to build the finest TV sets small enough to fit in a pocket or in a notebook, and wonderful talking motion-picture cameras the size of an ordinary book.

In a word, we want to subjugate the entire atom, to subordinate it to our will, to the will of victorious man who is transforming all the redoubtable and harmful natural forces into useful ones. We want to make all nature, the entire Mendeleyev table of elements serve the needs of working humanity.

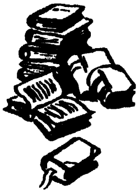
The aforesaid constitutes the purport and aim of geochemical work; that is why we want to understand and secure the atom.

With these words we are bringing our long story to an end.

But, dear friends, can there ever be an end to science or to studies? Let us be perfectly frank about it.

Here, at the very end of our book we, essentially, find ourselves at the very beginning of our knowledge; even if we read this book several times, carefully scrutinize all the pictures in it and try to remember the behaviour of the individual atoms we shall still have to admit we are only at the very beginning.

We shall have to read and think and work a lot more before we get an insight into the mysteries of nature around us.

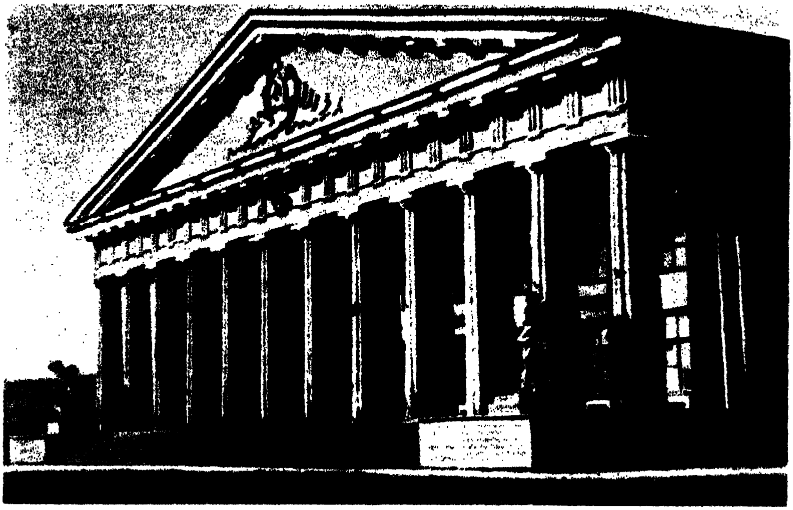


To begin with we must study the basic sciences—chemistry, physics, mineralogy and geology. We cannot circumvent these sciences and in order to become good students of the natural resources we must thoughtfully reread books on the principles of the chemical and mineralogical sciences.

We must read books carefully, delve thoughtfully into the fate of each element, study its behaviour in the earth, in water, in the air, in industry and in agriculture, and Mendeleyev's Periodic Table will always be our guiding star. Let us look at this table printed in this book or, what is even better, draw it on a large sheet of paper, put a chemical symbol and the atomic weight of a chemical element in each box and underneath each element write its content in the earth's crust and hang it in our rooms so that we always have it before our eyes.

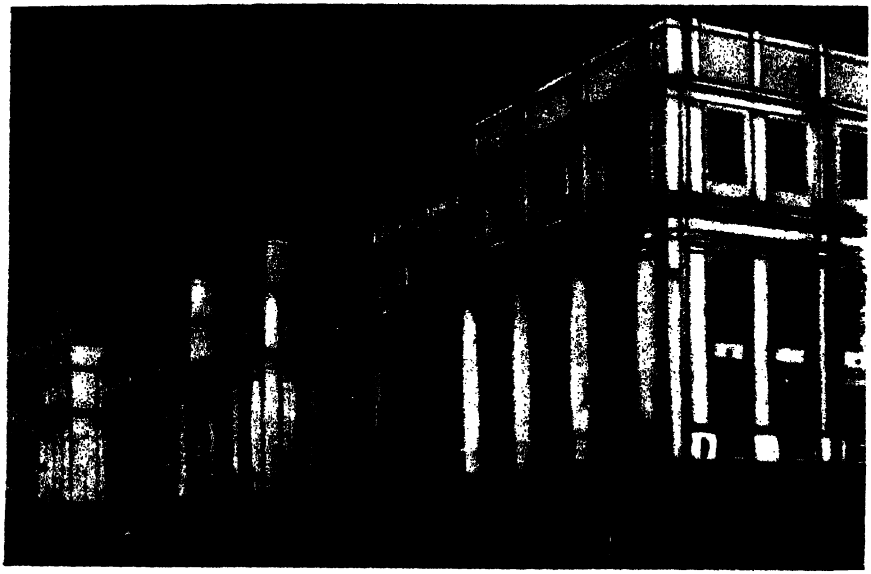
Mendeleyev's Periodic Law will teach us a great deal.

It will show us how the atoms are related to each other not only in the periodic table, but also in nature itself.



Leningrad Order of Lenin Mining Institute

Academician F. Chernyshov Museum of Geological Prospecting in Leningrad. Hall of Minerals



Exterior of the Chernyshov Museum of Geological Prospecting in Leningrad

Not only books, maps and tables, however, teach us chemistry and geochemistry. We can learn about the new ideas in chemistry in mineralogical museums where the exhibits in mineralogy and geochemistry in which the samples are frequently arranged according to separate chemical elements teach us a lot.

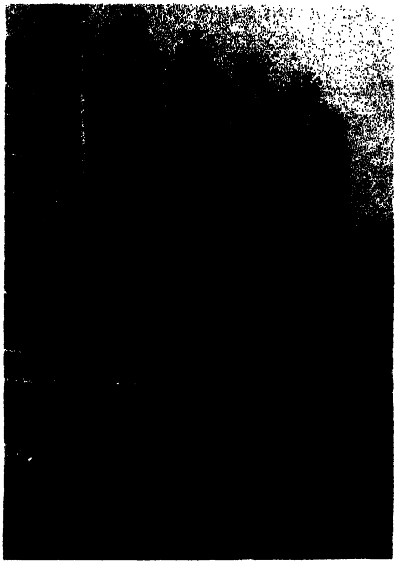
Large smelters and chemical mills also teach us chemistry, mineralogy and geology.

Anyone who has visited the Magnitogorsk Works will for ever remember what happens to iron ore and how first carbon-rich iron and then real steel are born in special shops from a complex combination of chemical elements processed in blast-furnaces. In Solikamsk we can learn about the chemical and geochemical fates of potassium and magnesium. At the superphosphate plants in Leningrad, Voskresensk (near Moscow), the Urals, the Ukraine and in other places we can see how apatites and phosphorites are transformed by means of sulphuric acid into fertilizer for our socialist fields.

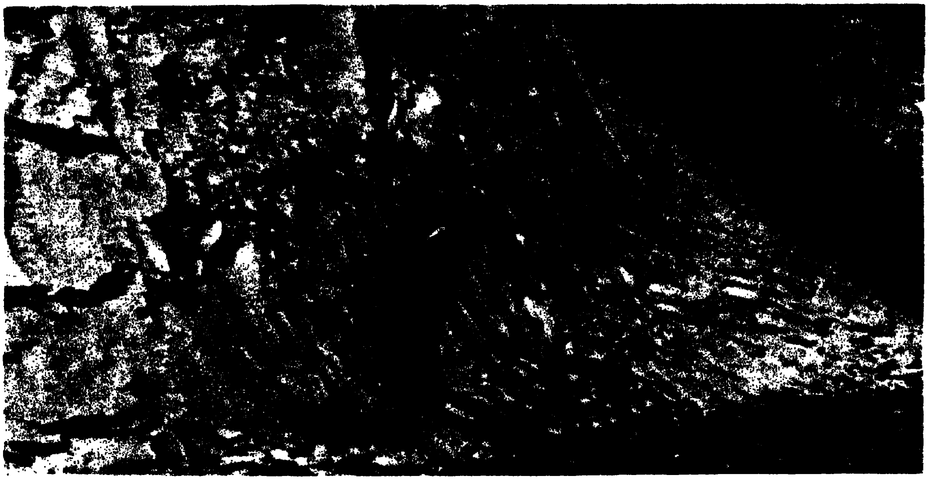
By observing the processes in the fire-breathing furnaces of the Chelyabinsk ferro-alloy plants we shall come to understand how molten magma is born in the interior of the earth and how substance is crystallized from this magma.

In a word, separate pages from the history of atoms are continuously rewritten at all large plants; these include the mixing of the atoms of various metals in complex processes and the extraction of different substances from them, which are later blended again in new combinations with other atoms in order to produce alloyed steels, complex superphosphates, salts of potassium, manganese, vanadium and zirconium.

Industrial processes make ever more extensive use of chemistry.



Metallurgical Plant



Geochemist studying rock outcrop—hardened lava streams

We are no longer content with grinding a stone into a pavement block or an arrow-head; we now strive to change it chemically in order to get the most valuable quality and combination of various substances.

We cast fine blocks for our new, improved pavements; we change the natural processes and transform natural substances into new values.

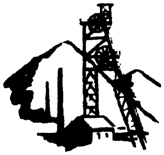
Today we are living not only in an epoch of chemical transformations, but also in a period of state-planned development of chemical research and chemical industry.

Chemical processes surround us on all sides and we must keep an eye on them and be able to divine them.

Nature itself, its deposits of metals, salts and ores also teach us geochemistry and give us new ideas in mineralogy. Nowhere will the young investigator learn the laws of chemical transformations as he will from nature itself, and we therefore appeal to all of them to study the chemical processes of the earth spring and summer, winter and autumn

By scrutinizing the black clays of the Jurassic deposits near Moscow we shall see how in early spring the golden sparklets of pyrite in them are absorbed by the faded light-green salts of vitriols. We shall see a grand picture of changes and transformations of iron ores in Mount Magnitnaya pit where at one time huge formations of magnetite on the earth's surface began to change first into brown masses of the mineral nontronite and were later covered with brown-red and rusty iron oxides.

Everywhere, in mines and quarries, on the tops of mountain ranges and in the deep valleys along rivers, we see how substance is being transformed, how one mineral changes into another and how a new substance is replaced by a still other substance. We must only be careful in our observations and we shall soon notice that everything changes, sometimes slowly and quietly, sometimes suddenly, subject to the great laws of nature. "Everything is fluid," the ancient Greek philosophers said. "Everything changes," say the geochemists of our time.



SUPPLEMENT

THE GEOCHEMIST IN THE FIELD

INTRODUCTION

This chapter consists of two parts. In the first part we set forth a number of practical suggestions for the geochemist who is prospecting for minerals and is making a geochemical study of some region. The second part briefly describes the basic methods in the sequence that should be observed by the geochemist in his field work.

Both the first and second parts are based on principles now closely adhered to by prospectors; scientific field work is generally comf posed of three parts: the preparatory stage, the investigation itsel- and the transport and treatment of the material.

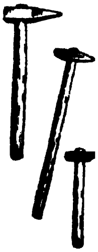
All these three parts are, no doubt, equally important and each of them requires attention and a thoughtful attitude.

Tents of geologists on the edge of the Kara-Kum Desert

"He who knows a lot and thinks a lot travels well," said a certain traveller and scientist, while another quite rightly added that the sharpest and the most important instrument an investigator must have at his disposal is his eye, which must not let even the most negligible phenomena escape because they not infrequently conceal extensive and important inferences.

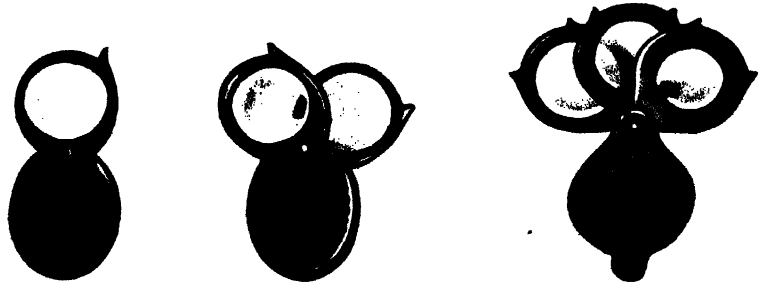
PART ONE

EQUIPMENT

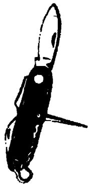


The problem of equipment in field work is very important to the geochemist because, in addition to the usual geological equipment, he will also need a number of other instruments for physical and chemical research. In this case it is necessary, first of all, to consider the means of conveyance on hand in the given region and the weight and size of the equipment. If a shortage of good equipment is sometimes dangerous for an expedition, in a number of cases, on the other hand, superfluous equipment is a drawback because it renders the movements of the expedition difficult and creates hardships that retard it and even prevent it from reaching certain inaccessible regions.

The total equipment of a prospector must primarily include different types of hammers. Sedimentary and soft rocks require a hammer which combines the properties of a hammer proper and a light pick; its handle must be approximately 40 cm. long and so fixed that its



Mineralogical magnifying glasses of different degrees of magnification narrow end will fit the hand while the wider end will prevent the hammer from coming loose in work. In the regions of hard rocks, the prospector should have a heavier hammer (weighing 1 to 2 kg.) with a handle about 70 cm. long. Centimetres should be marked on the handle in order that the investigator always have accurate scales for measurement at hand. In addition, extensive work requires a sledge hammer weighing up to five kg. and a small lightweight hammer with a short handle of about 20 to 30 cm. for knocking off small pieces or for shaping the samples. A set of chisels of various shape and size is required in addition to the hammers. The rest of the equipment should include a *magnifying glass* (magnifying no more than eight times), a mountain compass, a tape-measure, a pen-knife, a notebook and pencil, specially prepared and numbered labels 6 × 4 cm. in size, a lot of wrapping paper, some small glass jars for collecting valuable fragile samples and crystals, and strong boxes of different sizes; for dry substances it is important to have a set of small, numbered canvas bags.



In addition to the afore-said equipment, it is necessary to have a camera, an aneroid barometer and a set of coloured pencils for making geological and geochemical diagrams.

East Pamirs. Upper reaches of the Lyangar River

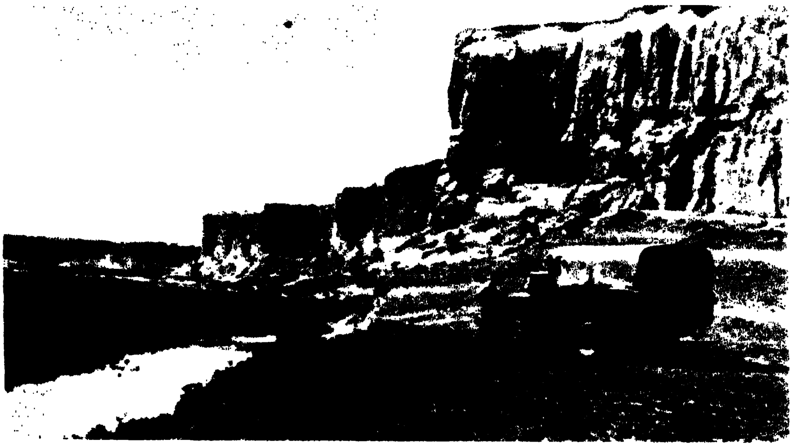
It is always good to have small bottles with acids of various concentration, good charcoal, platinum wire, soda and borax. For work of a more permanent nature this elementary equipment should be supplemented by a number of special instruments.

The packing and distribution of the equipment is a very serious affair. Part of it must be packed in strong, moisture-proof bags fit for being carried on the back (knapsacks), the other part must be packed in boxes suitable for the methods of transportation planned in the given region, and this requires a maximum of attention and experience to avoid blunders.

PACKING COLLECTED MATERIALS

The question of packing and transporting the collected mineralogical materials is very serious and must be given thorough consideration.

Careful packing and wrapping of each sample in separate paper with a label in it forms one of the "musts" of a good collection. You must make it your rule never to wrap several samples into one paper.



Steep loess bank of the Angren River near Tashkent however small they may be; each sample must always be wrapped separately. Negligence in packing often destroys well collected materials, especially samples of soft minerals. We should, therefore, distinguish the delicate and soft samples from the hard ones and pack them separately. Each sample must be wrapped in two or three sheets of paper, but these sheets must, under no circumstances, be folded together. The label for each sample, folded in two, should not be put directly on the sample, but rather after the first layer of paper; the labels must be inscribed in pencil (but, under no circumstances, in indelible pencil). Brittle and delicate brushes of crystals must first be covered by thin cigarette paper and a cotton tampoon and only then wrapped in large sheets of paper.

The materials collected by an expedition must be packed in a series of stages, each stage treated very carefully. The first stage is the daily collection and transportation of the materials to the camp. I worked out this method personally during my fifty years of experience. In collecting geochemical and mineralogical material all samples found by a certain group of workers must be carried to some definite place (near the camp) in much larger quantities than is required. Then, at the end of each workday (in the evening) all of the collected material is sorted, shaped, the best typical samples are selected and temporarily carefully packed in knapsacks. In the permanent camp, the samples are stored in a dependable and dry place and at the end of a certain period of work they are again examined and wrapped in paper for subsequent packing in strong boxes with the idea that each box weigh no more than 50 kg. Packing into larger boxes is not recommended because of the danger of crushing the stones; besides, during transportation and reloading very heavy boxes may easily be damaged. The materials should be shipped by the members of the expedition themselves. Leaving the samples in care of some of the local inhabitants puts the collections in jeopardy and they either get into the hands of the prospector very late, or not at all.

Upon arrival of the boxes the materials must be carefully assorted and the samples placed together with the labels into corresponding boxes, because a confusion of the labels may lead to irreparable damage and not infrequently to wrong and dangerous conclusions.

The first question that arises during a collection is: how much shall we take and in what shape? This question is rather hard to answer, and a good collection of mineralogical material can be ensured only by long experience and extensive knowledge of nature. Of course the prospector needs at least a modicum of artistic sense in order that the picked sample reflect by its form and colours precisely the mineral for which it was taken. Some samples must, therefore, never be given definite shape, while for others certain sizes (approximately 9 × 12 or 6 × 9 cm.) and shapes are desirable.

COLLECTION OF MATERIALS IN GEOCHEMICAL PROSPECTING

Geochemical prospecting and geochemical methods of research require that special material be collected. Since the subsequent work of geochemists is connected with special mineralogical, chemical, spectroscopic and X-ray studies, the collection of materials is a problem of prime importance and the success of geochemical analysis very largely depends on the quality and organization of the collection.

What must a collection of this type yield?

1) In the first place, a sufficient amount of materials not only for optical studies, but also for chemical analysis; in some cases detailed chemical analysis is preceded by concentration of the minerals during which the unnecessary admixtures are separated. Scores of samples of the most typical rocks and mineral combinations are, therefore, needed.

2) Mineralogical studies also require a collection of separate minerals to find out the sequence in which minerals are liberated and in order that good pure samples of the most important minerals may be selected for analysis.

3) It is necessary to collect materials not only for laboratory studies

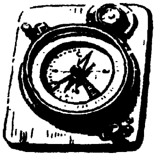
Crystals of black tourmaline

but also for retaining typical museum samples. This is important both for demonstrative purposes and because large typical samples make it possible to compare these minerals with samples of similar minerals, but from other deposits.

Crystals of gypsum

Comparative analysis is one of the research methods used by naturalists. A geochemist must not repeat the mistakes of the old mineralogical school; he must seriously consider even the slightest manifestations of every chemical element; even the thinnest crusts, products of weathering, must be collected as thoroughly as the beautiful ores with good crystals.

As a rule, prospectors are generally advised to take as much material as possible. It is better that they throw out later all that is superfluous rather than not collect all of the material required by the complex of minerals and chemical elements of the region studied.



In collecting samples one must never be sure he will come to the same place again and will collect additional new material. This does not always work out, and the collection is frequently incomplete, casual and of little value.

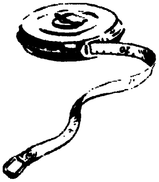
RECORDING OBSERVATIONS

The question of recording observations in field work is very important and serious. A certain scientist used to say quite justly that a traveller and explorer must carry a pencil tied to a string around his neck because the closer you have the pencil within your reach, the more you will write with it. The records must be made by two methods. In the first place, it is desirable accurately to inscribe on each label enclosed with the sample not only where and when the sample was found, but also some data on the conditions under which

Crystals of red garnet in mica slate

it was obtained. The more exactly the place of the find is indicated, the easier it will be subsequently to utilize the collected material.

The main records, however, are made in the field notebook and keeping the book in the best possible order must be the object of the prospector's constant concern. The success of many explorations depends on how carefully, thoughtfully and fully the field journals are kept. The observations must be recorded, first of all, at the place of work; the records must include all observations made in the given place and whatever thoughts occurred to the prospector at that time. A summary of all the material must be given at the end of the day with diaries kept of what was done during that time. Diagrams of the places where the work was done and the separate samples were taken should be made by the prospector in the notebook personally.



The completeness and accuracy of records in the notebook generally serve as the best index of the work, and one of the blunders of field workers is excessive reliance on their memory. Data added in the field book or on the labels by memory are a very dangerous method which not infrequently renders the collection valueless and leads to wrong inferences.

It will be observed that it is very difficult to keep a good field journal. Entries can usually be made in it only in the evening, at the end of a hard day in the field when the prospector is already tired and wants to rest. One must frequently force oneself to spend at least fifteen minutes on recording the observations made in the field during the day. I remember I also sometimes neglected my journal because I was too tired. In these cases it is best to take a day's rest and devote several hours to a calm and business-like correction of the journal.

Field journals must be kept particularly carefully; they must not be relinquished either during work or after it because they are the basic document which must always be carried along with the other most important documents of the expedition.

After returning from the expedition and sorting out the collections we come to the second part of our work, i.e., to summing up the results of the field work.

I believe it is very important and consider a field report in many respects more important than the final report, because it usually objectively summarizes the direct field observations and is, thus, more valuable than a detailed final report which is influenced by the literature read, by the opinions of other prospectors and by a number of extraneous considerations.

The report made under the first impressions of the trip is not infrequently much more correct and profound from the point of view of posing the problems than the later studiously thought-out and elaborated summary.

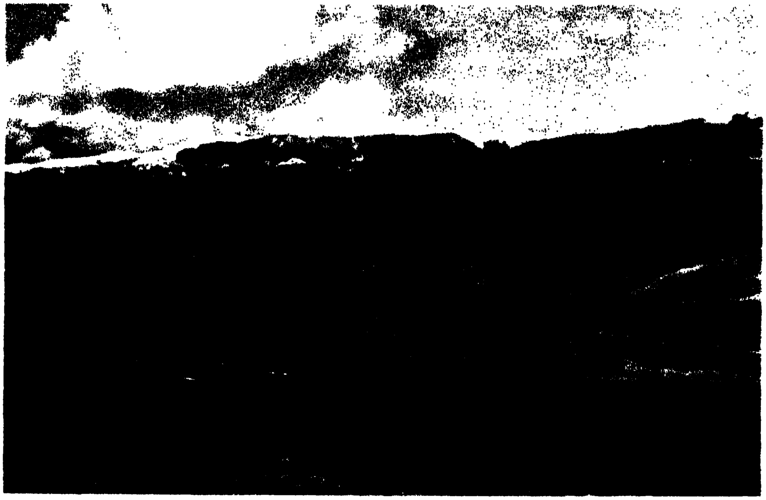
PART TWO

METHODS AND SEQUENCE OF WORK

Before leaving for the field the geochemist must do some preliminary work in addition to preparing his equipment which we have already discussed. This preliminary work consists in the following.

First of all, he must read the literature on the given region and the given problem. If the prospector is searching for a definite chemical element he must necessarily study in detail its properties and its compounds. In addition to reading the available literature the geochemist must, in all cases, make a detailed museum study of the samples typical of the given region and of the minerals which characterize the element, i.e., the object of his prospecting. It is particularly important that the investigator obtain detailed topographical and geological maps or copies of them, in order that he may mark in coloured pencil the route he has travelled and the locations of the most interesting minerals on these maps.

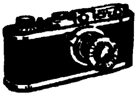
Before departing for the expedition, the prospector must necessarily make a detailed study of all the methods of field research and know



Characteristic relief in Dzhalal-Abad Region, Kirghiz S.S.R.

precisely not only how to use the instruments the geochemist takes along, but also how to repair them.

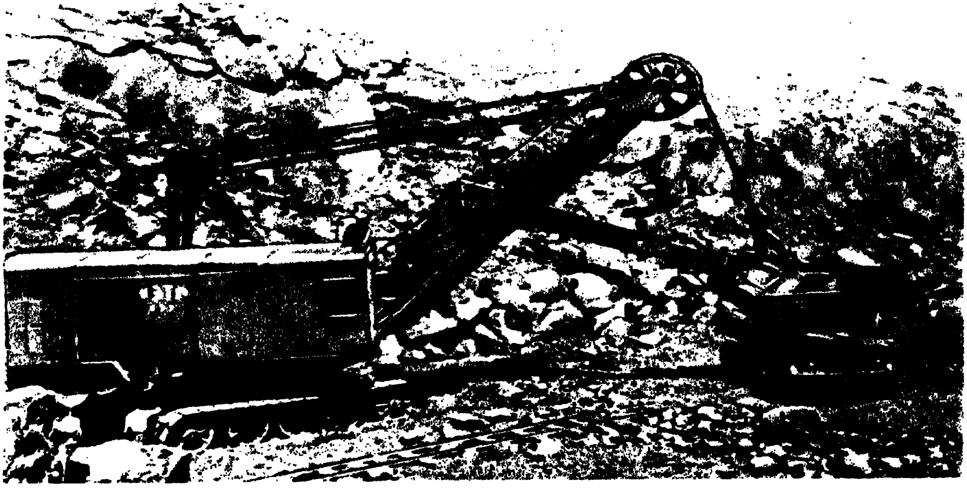
The second stage of work begins upon the arrival of the prospector on location. First of all, he must find out what is known about the given region in the local scientific societies, museums, libraries and schools. He must collect information among the local population about all the places where ore is mined and where there are natural outcrops. In a number of cases it is very important to analyze the geographical names which, not infrequently, point at the existence of mines or production in the given territory; for example, in Central Asia, the word "kan" means a mine, "kumysh"—silver, "kalba"—tin or bronze, etc. If a house is being built or a road paved, the prospector should find out-where the material is brought from and where the new road bridges or a railway line are built. On state and collective farms he must ascertain where they dig wells, where they obtain clay for their stoves and lime or paint for their homes.



The local population frequently remembers that research parties had worked in the given region before, and many old people who know the region very well remember the ores found in particular places. In some regions it is very important to ascertain the existence of old mines, dumps of ores and slags, remains of smelting furnaces, etc.

Of course, most of the material for the preliminary acquaintance with the mineralogy and geochemistry of a region is obtained not so much from natural outcrops as from artificial excavations, dumps near mines and workings which offer the mineralogist and geochemist indispensable and often perfectly fresh material. Ore deposits accumulate enormous quantities of the substances which accompany the ore and in the dumps of mines it is not infrequently possible to collect interesting material by examining the new output for a period of many days and by analyzing the minerals in daylight in the freshly broken-off samples. The dumps and heaps of mined ore and stone generally offer the mineralogist or geochemist much more valuable material than the underground workings where it is often hard to conduct accurate observations.

In open-cast mining and in pits it is very useful to talk to the workers, question them about the samples they encounter and focus their attention on interesting things, asking them to put away whatever strikes



Mining phosphorite ore at the Kara-Tau Mine (Kazakh S.S.R.)

Sarez Mountain Lake in the Pamirs formed after enormous landslide in the mountains (Tajik S.S.R.)

their eye. It is possible and necessary to get the local population interested by letting the people in on your work and by telling them of the use of the minerals which may be found. The creation of a definite public opinion, a sympathy and cooperation on the part of the local population is one of the most important factors in the success of prospecting. The local population becomes interested and even children bring samples of pebbles and boulders from the river. It must be said that the greatest discoveries of new deposits are not infrequently made by the local population and the local amateurs.

In each outcrop, quarry, working and mine the geochemist must try to collect the samples of all mineral bodies encountered there and pay attention to their large accumulations and negligible traces which may indicate some particular geochemical processes.

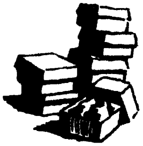
The collection of materials must, naturally, be accompanied by observations of the minerals imbedded in the rock, their correlations, age, etc. The primary acquaintance of the region enables the prospector to make a correct approach to its geochemical study. The following paragraphs are devoted to these problems of a purely research character.

The geologist and petrographer begin their work in the field with a study of the general geological situation, the tectonics and the relationships of rocks; this requires, in the first place, that the entire territory should be studied as a whole before a detailed study of any concrete sector is begun.

The work of the geochemist usually proceeds differently; he must begin his work essentially with concrete material, i.e., with the very deposit. He must begin his research from the heaps of the mined ore and the dumps of country rock with a ready knowledge of the general geological lay of the land. This indicates the rather sharp difference in the methods of approach to the work of geologists and geochemists in an expedition or excursion.

Upon arrival in some deposit the geologist immediately goes to a drift or mine to examine the faces; he also examines, in the first place, the outcrop of separate rocks, natural outcrops, etc.

The geochemist and mineralogist go, first of all, to the ore heaps and dumps. They must go into the stope only when their eye learns to distinguish separate materials in the daylight because determination of mineral species in the artificial lighting of the stope is a very hard task and is possible only with long experience. Only after a thorough study of the minerals in heaps and dumps must the geochemist begin studying the more general genetic and geochemical problems for which purpose he examines the natural outcrops and mine faces and studies any sketches that may be available.



This makes it perfectly clear why the mineralogist and geochemist upon arriving at a mine usually go first to the country rock dumps rather even than to the ore heaps.

I have personally observed that the local technical and engineering personnel is frequently not only surprised, but also very much displeased when, upon my arrival, I go to the dumps rather than to the workings. We must not forget that we can solve the most complicated problems of a deposit and understand its genesis only by a detailed study of all of the observed mineral complexes, their interrelations, their relations with the lateral rocks, etc.

Thus, the sequence of the work of a geochemist during the first collection of scientific material appears to us as follows: a detailed examination of the dumps and then of the ore heaps; later, of the faces in open-cast workings and outcrops; only after all that should he examine the underground workings and study the interrelationships of the minerals in the fresh underground stopes.

As previously stated, the geochemist must collect materials and concurrently analyze all mineralogical and geochemical interrelations; it is, therefore, necessary that he carefully compare all his observations. I recall that, when I advanced the theory of the relation of pegmatite processes to the formation of emeralds in the Emerald Mines I met with o sympnathy for a long time until several very small crystals

In the Pamirs At the source of the Murgab River

of columbite confirmed that we were dealing with typical granite pegmatites.

In thinking over his observations the geochemist must mentally establish relationships between separate minerals, reconstruct the conditions under which they were formed, basing himself on his experience, subject all the data to a comparative analysis and, thus, gradually evolve some *working hypothesis* about the genesis of the deposit in question. Such a hypothesis is absolutely necessary for subsequent prospecting, but it must not be allowed to obscure the facts themselves. If the facts disagree with the hypothesis, the latter must be rejected. This work requires the most profound self-criticism and self-analysis, because success in prospecting consists in the ability to draw out of small and hardly perceptible facts inferences which may be able to connect all phenomena to each other and to suggest those that are still unknown. Any working hypothesis is good only as long as it suggests new directions.

I am consciously focusing the reader's attention on this problem, because field workers are very frequently loath to give up their first working hypothesis even when new facts are at variance with it.

One more principle, which, unfortunately, has lately been somewhat neglected. The prospector must clearly distinguish the fact itself and his observation, on the one hand, from the theoretical and general conclusions, on the other. Both in his field and final reports the prospector must sharply separate these two parts so that everyone may see where the factual material of observations ends and where the logical and theoretical constructions of the author begin. Young prospectors should be warned against putting the concrete factual material in the background and becoming fascinated with the final conclusion, because in this case the conclusions hang in the air.

This is why we must especially persistently emphasize the necessity of accurate and painstaking observation of natural phenomena.

In the field the prospector must make note of every trifle that strikes his eye during observation. He must transform his field notebook into a constant diary of his own thoughts and observations, for only thus will he be able to make correct conclusions and decisions. Besides, he must sharply distinguish between the character of work and notes taken during the first year of visiting a particular deposit or region and that of the subsequent years. During the first visit it is especially necessary to accumulate purely factual material; during the second visit the prospector faces the necessity of checking on the work in his hypothesis; finally, during the third visit, he runs into problems of a general nature and it is usually precisely the third year that brings discoveries and suggests the direction of accurate prospecting. These periods may be cut short, but this depends on the experience of the prospector and on the extent to which the given deposits or region have been studied from the geological and mineralogical points of view.

The final conclusions are considerably expedited if the prospector analyzes beforehand the minerals and rocks he encounters during his field work. Portable geochemical laboratories and the possibility of sending certain samples to near-by laboratories for quantitative analysis in large measure facilitate the field studies and enable the prospector to expedite final conclusions.

It should be clear from the foregoing that the keeping of records is of prime importance.

BRIEF INFORMATION ABOUT CHEMICAL ELEMENTS

Actinium (Ac). Atomic number—89, atomic weight—227. Discovered in 1899 by Debierne in pitch-blende. Radioactive product of uranium disintegration with a 20-year half-life period. As a result of subsequent disintegration actinium successively forms a series of radioactive elements known as the actinium series. The final member of this series is non-radioactive lead with an atomic weight of 207. Very little is known about actinium and its compounds as yet.

Actinoids. Group of chemical elements following actinium and very closely resembling each other chemically. Like the rare-earth group, or lanthanoids, this group must contain 15 chemical elements from No. 89 to No. 103; twelve of them have already been discovered or produced artificially: these include actinium, thorium, uranium, neptunium, plutonium, americium, curium, berkelium, californium, einsteinium, fermium and mendelevium. The first three of these occur in nature.

The elements of this group are united under the name of "actinoids" ("actinides"). Their chemical properties very much resemble those of the lanthanoids and they are all crowded into a single box in the 3rd group of Mendeleyev's Periodic Table just below the rare-earth group.

Alabamine. D. Mendeleyev believed there was an element (ekaiodine) with an atomic number of 85 and described its properties. Discovery of an element with the atomic number 85 was reported in America in 1931, the element being named alabamine; the discovery was not confirmed, however, and element 85 did not retain the name alabamine. See *astatine*.

Aluminium (Al). Atomic number—13; atomic weight—26.98. Silvery-white, very light metal; constituent of clays, feldspars, micas and many other minerals. Most abundant element in the earth's crust after oxygen and silicon. The earth's crust contains 7.5 per cent of it by weight. The main mass of aluminium is concentrated in alumosilicates, minerals composed of aluminium, silicon, oxygen and certain metals. Bauxites—hydrous oxides of aluminium—are especially rich in aluminium. Aluminium is produced mainly from bauxite and from nepheline. Its alloys are extensively used in aircraft-building. First obtained in its pure state by Wöhler in 1827. The name stems from the word *alum*.

Americium (Am). Atomic number—95; atomic weight of the stablest isotope with a half-life period of about 10,000 years is 243. First obtained artificially by bombardment of uranium with alpha particles in 1945. Five isotopes are known today. In its chemical properties it is very similar to rare-earth metals.

Antimony (Sb). Atomic number—51; atomic weight—121.76. Known since antiquity. Produced in its free state by Basil Valentine in the 15th century. Very brittle metal. Occurs in combination with sulphur. Used as a constituent in type metal and in medicine. An addition of antimony to lead greatly increases its hardness, which is taken advantage of in the manufacture of type metal and bullets. Antimony compounds are used in the match, rubber and glass industries.

Argon (Ar). Atomic number—18; atomic weight—39.944; belongs to the group of inert gases which form no compounds either with each other or with any other substances, and thus sharply differ from all other elements. Owes its name to its passivity; argon means "inactive" in Greek. Discovered by Ramsay and Rayleigh in 1894. Encountered as a constituent of the air which contains about one per cent of it. Used for filling luminescent tubes; emits a bluish light.

Arsenic (As). Atomic number—33; atomic weight—74.91. Brittle, brown-black volatile metal with a garlic-like odour. The name of the element stems from the word *arsenicon*, meaning mineral dye. Known since hoary antiquity. Sublimates without melting at 633° C. Melts at 818° C. and under a pressure of 36 atmospheres. Arsenic and its soluble salts are poisonous. Used in alloys with lead and copper; forms a constituent of the substances used in fighting agricultural pests (fungicides); employed in glass manufacture for decolourizing glass.

Astatine (At). Atomic number—85; atomic weight of its longest-lived isotope with a half-life period of 8.3 hours is 210. First obtained in 1940 by bombardment of bismuth with alpha particles. Named after *astatos*, the Greek word meaning "unstable." 20 isotopes are known. Its properties quite coincide with D. Mendeleyev's predictions; Mendeleyev had named it ekaiodine.

Barium (Ba). Atomic number—56; atomic weight—137.36. Silvery-white metal as hard as lead. Discovered in 1774 by Scheele; first produced in its pure state by Davy in 1808. The name comes from the mineral barite, from which it was produced (*barus*—heavy). Colours the flame a characteristic yellow-green. Its salts are used as a good white paint.

Berkelium (Bk). Atomic number—97. Produced artificially by bombardment of the isotope of americium with an atomic weight of 241. The half-life periods of the berkelium isotopes thus far discovered do not exceed a few hours. Named after the city of Berkeley in the State of California (U.S.A.).

Beryllium (Be). Atomic number—4; atomic weight—9.013. Very hard but light white metal (its specific gravity is 1.85); stable in the air. Discovered in 1797 by Vauquelin and named by him glucinum because of the sweetish taste of its salts. This name has persisted only in France. The word "beryllium" comes from the mineral beryl. Used for alloys with copper (beryllium bronzes) and other metals; makes these alloys hard as steel and "tireless" under stress (watch springs). Large concentrations of beryllium minerals are rare.

Bismuth (Bi). Atomic number—83; atomic weight—209. Reddish-white, brittle, fusible metal. Compounds of bismuth were known in antiquity but at that time it was not distinguished from lead; first isolated in its native state by alchemist Basil Valentine in the 15th century. Forms part of the alloys used in printing and in different fire-fighting devices; interesting for its superconductivity of current at temperatures approaching absolute zero.

Boron (B). Atomic number 5; atomic weight 10.82. Discovered in 1808 by Davy in England and by Gay-Lussac and Thénard in France. The name comes from the word "borax." Crystalline boron isolated from the alloy with aluminium is almost as hard as diamond. Occurs as boric acid and borax and in certain silicates (salts of silicic acid). Used mainly for the manufacture of enamels and in medicine. The compounds of boron with carbon and nitrogen are extraordinarily hard.

Bromine (Br). Atomic number 35; atomic weight 79.916. Discovered by Balard in 1826 and named bromium (*bromos* stinking) because of its unpleasant odour. Bromine is a dark-brown heavy liquid; like all the halogens it is extraordinarily active and enters into combination with most of the elements. Reacts particularly vigorously with metals. Produces severe burns upon contact with the skin. Encountered mainly in compounds with potassium, sodium and magnesium. The salt-lakes of the Crimea are rich in bromine. Used in medicine and in the photo industry.

Cadmium (Cd). Atomic number 48; atomic weight 112.41. Silvery-white metal discovered by Strohmeyer in 1817; name derived from the Greek word *cadmes*—zinc ore. Closely resembles zinc in properties and always accompanies it in nature. Used instead of zinc for plating iron, in alloys with copper for enhancing the strength of copper wires, in fusible alloys and yellow paint manufacture.

Calcium (Ca). Atomic number—20; atomic weight 40.08. Alkaline-earth metal. Discovered by Davy and Berzelius in 1809. Name comes from the word *calx*—soft stone (limestone); malleable, rather hard white metal; melts at about 800° C. and boils at 1,240° C.; abundant in nature in the form of carbonates, sulphates and silicates. Its average content in the earth's crust is 3.4 per cent. Only 4 elements (O, Si, Al and Fe) are encountered in nature in larger amounts than calcium. Metallic calcium has not found any special application as yet.

Californium (Cf). Atomic number—98. Artificially obtained by bombardment of the isotope of curium (atomic weight—242) with alpha particles. The half-life period of californium (atomic weight—246) is 35 hours. Named after the State of California, U.S.A.

Carbon (C). Atomic number—6; atomic weight 12.011. Known since early antiquity. Name derived from Latin *carbo* coal. Occurs in the form of diamonds, graphite, coal, various hydrocarbons (oil and natural gases) and in organic substances. Most of it, however, is in carbonates (salts of carbonic acid)—limestones, marbles, etc., as well as in solutions with water and air (in the form of carbon dioxide). Applications: diamond—for boring, cutting and grinding glass, for decorations; graphite—as a refractory material (graphite crucibles), lubricant, powder, in pencils, in rheostats and in electrodes for arc electric furnaces; coal and oil are used as fuel, as one of the most important sources of energy. Carbon black is used in paints (Indian ink). Coal processing yields numerous chemical products including aniline; drugs (aspirin and streptocide); saccharine; explosives (trinitrotoluene), etc.

Cassiopeium (Cp). Name used in some countries for the element lutecium. See *lutecium*.

Cerium (Ce). Atomic number 58; atomic weight 140.13. Rare-earth element. Discovered in 1803 by Hisinger, Klaproth and Berzelius and named after the small planet Ceres. Cerium forms part of the mixture used in the manufacture of flints for cigarette-lighters, in medicine, and in artillery for tracer shells. It is extracted from monazite as a by-product in the production of thorium.

Cesium (Cs). Atomic number 55; atomic weight 132.91. Alkali metal. Specific gravity 1.87; melting point 28.5 C. Named after the sky-blue colour of the spectral lines characteristic of cesium (*caesius* in Latin blue sky). First of the elements discovered by spectral analysis (Bunsen in 1860). Colours the test flame violet. Only one cesium mineral pollucite is known. Cesium is used as the main constituent in photocells.

Chlorine (Cl). Atomic number 17; atomic weight 35.457. Discovered by Scheele in 1774; name derived from the word *chloros* green. Yellow-green gas heavier than air. Occurs in salts of sodium and potassium dissolved in the waters of the ocean, or in rock salt (NaCl) deposits. One of the basic elements of the chemical industry mainly for the production of chloride of lime; plays a very important part in the manufacture of paints, many drugs and poison gases. Large quantities of chlorine are used in bleaching fabrics and paper, in sterilizing drinking water and in fighting agricultural pests. Sodium chloride (NaCl) is used in enormous amounts in food (every human being consumes from 2 to 10 kg. of salt a year).

Chromium (Cr). Atomic number 24; atomic weight 52.01. Discovered by Vauquelin in 1798 while he was decomposing the mineral crocoite brought by Pallas from the Urals. Name stems from the Greek word *chrome* colouring because of the motley colours of its different compounds. Very brittle, hard and very stable against air and water; specific gravity 7.1; melts at 1.765 C. Most frequently encountered in the mineral chromite. Used mainly in the steel industry. Chromium steels are known for their hardness and durability; they are used for the manufacture of tools and gun tubes. Other metals are chromium-plated in order to prevent them from corrosion.

Cobalt (Co). Atomic number 27; atomic weight 58.94. Discovered by Brandt in 1735 and named after the word *cobold*, meaning mountain spirit or gnome. Rather hard greyish-white, malleable and ductile metal; melts at 1.490 C.; magnetic, but less so than iron; in a pulverized state capable of absorbing large amounts of hydrogen; resembles iron physically and chemically. Occurs in meteorites (in alloys with nickel and iron) and in the earth's crust in combination with arsenic and sulphur. Used in the production of special steels, as a blue dye for glass and enamels and as a catalyst in producing motor fuel from coal.

Copper (Cu). Atomic number 29; atomic weight 63.54. Red, malleable metal. Known since early antiquity. Named after the Island of Cyprus because of the extensive production of copper wares on the island in antiquity. Occurs mainly in combination with sulphur, more rarely native. Used in its pure form in electrical engineering and is one of the best conductors of heat and electricity; also widely used in alloys with tin and zinc (brass).

Curium (Cm). Atomic number — 96. Produced artificially in 1944. Eight isotopes of curium are known today. The longest-lived isotope is the one with the atomic weight of 245. Its half-life is more than 500 years; chemically resembles the rare-earth elements. Named in honour of Marie and Pierre Curie and of Frédéric and Irène Joliot-Curie.

Dvi-manganese. See *rhenium.*

Dysprosium (Dy). Atomic number — 66; atomic weight — 162.46. Rare-earth element. Discovered by Lecoq de Boisbaudran in 1886. Named after the Greek word *dysprositos* — difficult of access.

Einsteinium (En). Atomic number — 99. Radioactive element of the actinide series. Synthesized by a group of American physicists in 1953. Five isotopes of einsteinium have been obtained to-date. Named in honour of the great German scientist A. Einstein.

Ekaaluminium. See *gallium.*

Ekaboron. See *scandium.*

Ekacesium. See *francium.*

Ekaiodine. See *astatine.*

Ekamanganese. See *technetium.*

Ekasilicon. See *germanium.*

Erbium (Er). Atomic number — 68; atomic weight — 167.2. Rare-earth element. Discovered by Mosander in 1843 and named after the town of Ytterby.

Europium (Eu). Atomic number — 63; atomic weight — 152. Rare-earth element. Discovered by Demarçay in 1901. Its salts are coloured pink.

Fermium (Fm). Atomic number — 100. Radioactive element of the actinide series. Obtained in the U.S.A. in 1953 by fission of the products resulting from irradiating uranium with a momentary stream of neutrons. Named in honour of the Italian physicist E. Fermi. Four isotopes of fermium with a half-life period of 30 minutes to 16 hours have been synthesized to-date.

Fluorine (F). Atomic number — 9; atomic weight — 19.00. Halogen-family non-metal. In its free state it was first isolated by Moissan in 1886 though it had been taken for an element by Ampere as early as 1810. The name stems from the name of the mineral fluorite. Normally it is a gas, greenish-yellow in its heavy layers. Specific gravity — 1.11 (liquid); melts at 223 C.; boils at 188 C. Finds no application in its free state. Hydrofluoric acid is widely used in chemical laboratories as well as in etching glass.

Francium (Fr). Atomic number — 87; first discovered by the Frenchwoman M. Perey in 1939 in the natural radioactive series of actinium disintegration; later produced artificially. The brief existence of the isotopes of francium makes it difficult to study its chemical properties. The atomic weight of one of its isotopes is 223. In its properties it is akin to cesium and is one of the most active metals. Named after the native land of the investigator. The existence of francium was assumed by D. Mendeleyev who described it under the name of ekacesium.

Gadolinium (Gd). Atomic number — 64; atomic weight — 156.9. Rare-earth element. Discovered by Marignac in 1880; named after the mineral gadolinite in 1886.

Gallium (Ga). Atomic number — 31; atomic weight — 69.72. One of the elements whose properties were predicted by D. Mendeleyev (ekaaluminium). Discovered by Lecoq de Boisbaudran in 1875 by the spectral method and named in honour of France whose old name was Gallia. Silvery-white soft metal with very low melting temperature of 29.8° C. (melts in the hand), but with a boiling temperature of 2,300° C.; solid gallium is lighter than liquid gallium and therefore floats in its own melt; belongs to the rare dispersed elements; used in the manufacture of thermometers for measuring high temperatures and luminous compounds; also used in the production of optical mirrors.

Germanium (Ge). Atomic number—32; atomic weight—72.60. One of the rarest elements whose properties were predicted by D. Mendeleyev (ekasilicon). Discovered in 1886 by Winkler by the spectral method. Possesses both metallic and non-metallic properties. Finds application in radio-engineering for the manufacture of luminous compounds and for the production of special sorts of glass.

Glucinum (Gl). See *beryllium*.

Gold (Au). Atomic number—79; atomic weight—197.2. Known since hoary antiquity. Malleable and soft metal; resists oxidation; dissolves only in aqua regia; does not readily form compounds with other elements; only its alloys with silver and its compounds with selenium and tellurium are known. Specific gravity of chemically pure gold is 19.3 (of native gold containing from 15 to 25 per cent silver—15 to 16). Melts at 1,060° C. and boils at 2,677° C. Thin leaves of gold show up green. Gold is a currency metal and this constitutes its main value. Its technical applications are insignificant; contacts, gold-plated articles, photography and medicine.

Hafnium (Hf). Atomic number—72; atomic weight—178.6. Though a more abundant element than gold or silver and its content in some minerals amounts to 30 per cent, it was discovered only in 1923 by Coster and Hevesy. This was due to the extraordinary resemblance of its chemical properties to those of zirconium from which hafnium can be separated only with difficulty. Metallic hafnium is very hard and has a high melting point (about 2,200° C.). In the form of oxides it constitutes part of the alloys used in the manufacture of electron valve filaments. Finds limited use in the radio industry as super-fireproof material. Its name comes from the ancient name of the Danish capital Copenhagen (Hafnia).

Helium (He). Atomic number—2; atomic weight—4.003. Noble gas. First spectroscopic lines discovered by J. Jannsen in 1868 in the atmosphere of the sun. On earth discovered by Ramsay in 1895; the latter isolated this gas from the mineral cleveite. The name comes from the word *helios*—sun. Second lightest of all gases after hydrogen; it is 8 times as light as air. Found in the atmosphere and together with other natural gases in the interior of the earth; formed during radioactive disintegration of elements; the alpha particle which comes flying out of the atomic nuclei of radioactive elements is a positively charged nucleus of helium; used together with hydrogen for filling dirigibles; prevents the latter from exploding. Lowest temperature on earth, nearly —273° C., has been obtained by evaporating helium.

Holmium (Ho). Atomic number—67; atomic weight—164.94. Rare-earth element. Discovered by the Swedish chemist Cleve in 1879. Holmium salts are pink-coloured. Named after the Swedish capital Stockholm.

Hydrogen (H). Atomic number—1; atomic weight—1.008. Lightest and first element in the periodic system of elements. Constitutes about 1 per cent of the entire mass of the earth's crust, including water and the air. Colourless gas, fourteen times as light as air. Discovered in the first half of the 16th century by Paracelsus as a result of the reaction between sulphuric acid and iron. In 1766 Cavendish discovered its properties and pointed out its differences from the other gases. Lavoisier was the first to produce hydrogen from water in 1783 and to prove that water was a chemical compound of hydrogen and oxygen. On the earth hydrogen occurs only in compounds (in water, oil and in the tissues of living cells; in its free state it is found in insignificant quantities in the upper layers of the atmosphere; also liberated during volcanic eruptions. Spectroscopically discovered in the sun and in the stars. According to modern conceptions, the substance of the cosmos consists of 30 to 50 per cent free hydrogen whose atom is the principal building brick of the universe. In addition to hydrogen with an atomic weight of 1 there are two rare isotopes with atomic weights of 2 and 3 which in combination with oxygen yield "heavy water." Hydrogen is used for filling dirigibles and balloons in which it acts as the lifting force because it is lighter than air. In autogenous welding its flame develops a temperature of up to 2,000° C.; it is also used in the chemical industry for producing artificial oil from coal.

Illinium (Il). An element with an atomic weight of 61 was described under this name. The fact of its discovery was not confirmed. See *promethium*.

Indium (In). Atomic number—49; atomic weight—114.76. Rather rare dispersed element. Discovered by the spectral method by Reich and Richter in 1863; named after the dark-blue, indigo-coloured lines in its spectrum. Silvery-white metal softer than lead in its free state; no minerals rich in indium are known; ores of many metals contain insignificant admixtures of its compounds, especially with zinc. Best metal for the manufacture of mirrors.

Iodine (I). Atomic number—53; atomic weight—126.92. Dispersed element. Typical non-metal. Usually solid, volatile and easily soluble in a number of solvents. Discovered by Courtois in 1811. Produced in industry from Chilean saltpetre in amounts of up to 1,000 tons a year; also encountered in mineral oil waters and extracted from seaweeds. Name derived from the Greek word *iodis*—violet because of the colour of its vapours. Finds extensive application in medicine, roentgenotherapy, manufacture of polarizing glass, photography and in dyes.

Iridium (Ir). Atomic number—77; atomic weight—193.1. One of the heaviest metals (specific gravity—22.4). Discovered by Tennant in platinum ores in 1803. Name derived from the word *iridis*—iridescent (because of the particoloured solutions of its salts); noted for its great hardness and chemical stability; melts at 2,454° C.; chemically closely resembles rhodium; occurs as a fellow-traveller of platinum; used in its pure state for crucibles, high-temperature electric furnaces and thermoelements; also extensively used in alloys.

Iron (Fe). Atomic number—26; atomic weight—55.85. Known since early antiquity. Easily oxidizes and freely combines with other elements and is, therefore, hard to obtain in its pure state. Metallic iron is steel-grey and malleable; has the highest magnetic properties of all metals. Compounds of iron and carbon (steels, containing from 0.2 to 2 per cent carbon, and pig irons containing from 2.5 to 4 per cent carbon) form the basis of the iron and steel industry of our age. The principal ores are hematite—Fe_2O_3, magnetite—Fe_3O_4, iron carbonate or siderite—$FeCO_3$ and hydrous oxides of iron—$Fe_2O_3nH_2O$. The earth's crust contains 4.7 per cent iron; the cosmos contains more. Rocks with more than 30 per cent iron are iron ores.

Krypton (Kr). Atomic number—36; atomic weight—83.66. Inert gas discovered by Ramsay and Travers in 1898; name derived from the Greek word *kryptos*, meaning hidden. Occurs as a constituent of the air in which it is contained in negligible quantities.

Lanthanum (La). Atomic number—57; atomic weight—138.92. Rare-earth element. Discovered by Mosander in 1839; name derived from the Greek word *lanthenein*, meaning hide; constituent of the alloy used for "flints" in cigarette-lighters.

Lanthanoids (lathanides). See *rare-earth elements*.

Lead (Pb). Atomic number—82; atomic weight—207.21. Known since early antiquity. Bluish-grey, soft, heavy metal. Specific gravity 11.34; melts at 327° C. Has many uses. Used chiefly in the manufacture of cable sheathing and storage-battery plates; a large amount of it is used in the manufacture of bullets and shot. Constituent of many alloys: babbits, type metals, etc. Compounds of lead are used as a white paint. Occurs mainly in galena (PbS) from which lead is extracted.

Lithium (Li). Atomic number—3; atomic weight—6.940. The lightest metal. Lighter than water (specific gravity—0.534). Discovered by Arfvedson in 1817; name derived from the Greek work *lithos* (stone). Belongs to the group of alkali metals and is known for its very high chemical activity; closely resembles potassium and sodium chemically. Its salts colour the test flame bright red. Encountered only in compounds; traces of it are found in the waters of many mineral springs. Used in the manufacture of batteries for submarines, in special alloys and in welding aluminium wares.

Lutecium (Lu). Atomic number—71; atomic weight—174.99. Rare-earth element. Discovered simultaneously by Urbain in France and by Auer in Germany. The former named it lutecium after the old name of Paris; the latter gave it the name of cassiopeium. Both names are used in literature. The name used in the Soviet Union is lutecium.

Magnesium (Mg). Atomic number—12; atomic weight—24.32. Alkaline-earth metal. Discovered by electrolysis by Davy in 1808. Named after the mineral *magnesia alba*. (Magnesia is a locality in Greece; *alba* means white.) Abundant in nature; constitutes 2.5 per cent of the weight of the earth's crust and is a constituent of carbonate and silicate rocks. Enormous amounts of dissolved magnesium salts are found in sea-water; light (specific gravity—1.74) and malleable; very active chemically, but stable in alloys. Has found considerable application in the aircraft industry in the form of magnesium-aluminium alloys.

Manganese (Mn). Atomic number—25; atomic weight—54.93. A silvery-white, hard metal. Discovered by Scheele in 1774 in the mineral pyrolusite (native manganese dioxide sometimes called *black* magnesia, hence the name of the element). Very abundant in nature; forms accumulations of black pyrolusite in marine sediments. Used in metallurgy for improving the quality of steel, in the paint industry and in many branches of the chemical industry.

Masurium. Discovery of an element with the atomic number of 43 was reported in 1924. This discovery is not recognized today. See *technetium.*

Mendelevium (Mv). Atomic number 101. Obtained in the U.S.A. in 1955 by bombarding einsteinium 253 with high-energy alpha particles. Named in honour of the Russian chemist D. Mendeleyev.

Mercury (Hg). Atomic number—80; atomic weight 200.61. The only metal found in a liquid state under normal conditions. Known since early antiquity. Latin name (hydrargyrum) stems from the Greek words *hydor argyros* (liquid silver). Solidifies at −39.3° C.; boils at 357° C. Specific gravity 13.6. Dissolves many metals (gold, silver, copper and tin) yielding liquid and solid alloys called amalgams. Its vapours are very poisonous. Used in filling various instruments (for example, thermometers), in medicine, in extracting gold from ores and in manufacturing mercury fulminate, one of the most important detonators. Encountered in the mineral cinnabar (HgS).

Molybdenum (Mo). Atomic number 42; atomic weight—95.95. Greyish-white metal, hard and malleable at a high temperature. Discovered by Hjelm in 1782, but pure molybdenum was produced by Moissan only in 1895. The name stems from the Greek word *molybdos*, meaning lead, because of the resemblance of the latter to the mineral molybdenite. Found mainly as molybdenite or molybdenum disulphide (MoS_2), a mineral which externally resembles graphite. Metallic molybdenum is used in steel alloys to make them very hard and durable. Its alloy with tungsten replaces platinum. Also used as an anticathode in Roentgen tubes and for the anchors that support the tungsten filament in electric bulbs. Combines with carbon to form the carbide MoC_2, a very hard product.

Neodymium (Nd). Atomic number—60; atomic weight—144.27. Rare-earth element. Discovered by Auer in 1885 as a result of splitting didymium, formerly considered an element, in two: neodymium (new twin) and praseodymium. Neodymium salts are pink-red.

Neon (Ne). Atomic number—10; atomic weight—20.183. Noble gas discovered by Ramsay and Travers in 1898 simultaneously with krypton and xenon. Name derived from the Greek word *neos*—new. Encountered as a negligible admixture in the air. Used for filling gas-light lamps (neon lamps) which emit a red light.

Neptunium (Np). Atomic number 93. First of transuranium elements. Produced artificially in 1940 by bombardment of uranium with neutrons. Radioactive. 12 isotopes are known today; the longest-lived isotope is the one with an atomic weight of 237; its half-life is 2.2 million years. Chemically resembles uranium. Named after the planet Neptune. Occurs in negligible quantities.

Nickel (Ni). Atomic number 28; atomic weight 58.69. Silvery-white, rather hard metal. The name stems from the mineral *Kupfernickel* which means worthless copper. Discovered by Cronstedt in 1751. Melts at 1,455° C. Occurs in combination with sulphur or in silicate ores. Widely used for nickel-plating, in the manufacture of special steels and as a catalyst.

Niobium (Nb). Atomic number—41; atomic weight—92.91. Greyish-white, hard and malleable metal. Discovered by Hatchett in 1801 and named columbium by the discoverer. In 1846 Rose divided columbium into two elements—niobium and tantalum. The name *columbium* persists in America, while *niobium* prevails in the European countries. Named after the nymph Niobe, the daughter of Tantalus. Obtained in its pure state in 1907; extraordinarily stable against various chemical influences. Found closely associated with tantalum and titanium. Used in special alloys and in steels for the manufacture of very important welded structures since the addition of niobium greatly enhances the strength of welded seams. Employed in the production of superhard alloys; offers serious advantages for electro-vacuum engineering.

Nitrogen (N). Atomic number 7; atomic weight 14.008. Colourless gas constituting 4/5 of the volume of the surrounding air. First indications of the existence of nitrogen as a separate substance were made by Rutherford (1772), but it was only Lavoisier who proved that it was an element and who gave it the name of azote (the Greek for "lifeless"). The Latin name Nitrogenium and the modern English name nitrogen originated from *nitron* (saltpetre) and genus. In addition to the air, nitrogen is found in all living organisms, as well as in the form of the saltpetres, i.e., the nistrate of sodium and potassium. Free nitrogen is used in electric lamps; its compounds are of enormous importance as fertilizers and as constituents of explosives.

Osmium (Os). Atomic number 76; atomic weight 190.2. Belongs to the group of platinum metals. Discovered by Tennant in 1803; name derived from the Greek word *osme*—odoriferous because the vapours of osmic anhydride smell of rotten radish. Chemically very stable element. Specific gravity of 22.48, is the highest of all the substances on earth. Melts at 2,500° C. Occurs in its native state together with platinum. Alloy of osmium and iridium is uncommonly hard and is used for tips of fountain pens.

Oxygen (O). Atomic number 8; atomic weight 16.0000. The name literally means "acid former." Discovered by Priestley in 1774. Extraordinarily abundant in nature, constituting 49.5 per cent of the earth's crust by weight. Plays an enormous part in natural processes: constituent of water, most minerals and organisms; widely used in metallurgy (in the smelting of pig iron), in autogenous welding and in a number of branches of the chemical industry; liquid oxygen or liquid air are used as powerful explosives.

Palladium (Pd). Atomic number 46; atomic weight 106.7. Element of the platinum group. Discovered by Wollaston in 1803 and named in honour of the small planet (asteroid) Pallas. Softest and most malleable of all the elements of the platinum group. Remarkable for its ability to absorb tremendous amounts of hydrogen (up to 300 volumes per one volume of the metal) while retaining its metallic appearance but increasing in volume. Used in jewellery because of its beauty.

Phosphorus (P). Atomic number 15; atomic weight 30.975. Received its name because of its luminescence (from the Greek words *phos* light and *phoros* bearing). Discovered by Brandt in 1669. Specific gravity 1.83; melts at 44° C.; boils at 280.5° C. The following varieties are known: yellow phosphorus, red phosphorus; in 1914 Bridgeman produced black phosphorus. Abundant in the earth's crust in the form of phosphates; constituent of numerous minerals: apatite, turquoise, iron phosphates, copper phosphates, etc. Used in the manufacture of matches, in the production of smoke-screens, kindling substances, etc. Phosphorites and apatite are the most important raw materials for the production of phosphorus-containing fertilizers.

Platinum (Pt). Atomic number =78; atomic weight=195.23. Chief element of the platinum group. Discovered by Antonio Ulloa in 1838 in the gold-bearing sand of the Pinto River; as an independent element described by Watson in 1750. Name stems from the Spanish word *platina*, a diminutive of *plata*—silver. Specific gravity=21.4; melts at 1,773.5° C. Shining, malleable metal; does not change in the air even when heated to the highest possible temperature. As a refractory and chemically stable element finds extensive application in scientific and technical laboratories. Occurs native. Mined mostly in placer deposits.

Plutonium (Pu). Atomic number=94. First artificially produced in 1941 by bombardment of uranium with deuterium nuclei of heavy hydrogen. Radioactive. 12 isotopes are known today. The longest-lived isotope is the one with an atomic weight of 242. Its half-life is 500,000 years. Isotope 239 is the basic product for obtaining atomic energy; chemically resembles uranium. Named after the planet Pluto. Found as a negligible admixture in native uranium ores (about 1 atom of plutonium per 140,000 million atoms of uranium).

Polonium (Po). Atomic number=84; atomic weight=210.0. Radioactive element. Discovered by Marie Curie in 1898 and named in honour of her native Poland. Has not been produced in its pure state. Chemically very closely resembles tellurium and is a member of the uranium series of radioactive elements. Its half-life is 137.6 days.

Potassium (K). Atomic number=19; atomic weight=39.096. First isolated by electrolysis from caustic potash by Davy in 1807. Latin name (kalium) comes from the arabic word *alkali*; English name—from potash. Does not occur native but is very abundant in silicates and halides. The potassium isotope having an atomic weight of 40 is radioactive. Potassium is a silvery-white metal, soft as wax; oxidizes rapidly in the air and is, therefore, kept in kerosene. Melts at 63.5° C., boils at 762° C. It is lighter than water (specific gravity=0.862). With sodium yields an alloy which is liquid at usual temperatures and which can replace mercury in thermometers. Metallic potassium finds very little application because it is replaced by cheaper sodium.

Praseodymium (Pr). Atomic number=59; atomic weight=140.92. Rare-earth element. Discovered together with neodymium by Auer in 1885. Name derived from the Greek words *praseos* and *didymos*—green twin. Its salts are green.

Promethium (Pm). Atomic number=61. In Mendeleyev's periodic system located in the group of rare-earth elements. Chemically isolated from fragments of uranium fission as a relatively long-lived isotope with an atomic number of 147. Its half-life is close to 4 years. Named in honour of the mythological titan Prometheus.

Protactinium (Pa). Atomic number=91; atomic weight=231. Silvery-white metal. Radioactive element. Discovered by Hahn and Lise Meitner in 1917. In 1927 Grosse isolated a fraction of a gram of free protactinium. Name derived from the Greek words *protos* and *actinos*—first ray. Occurs together with uranium and is one of the products of its disintegration. Its half-life is 3,200 years.

Radium (Ra). Atomic number=88; atomic weight=226.05. Silvery metal which decomposes water at ordinary temperature. Radioactive element of the uranium series discovered by the Curies in pitch-blende in 1898. Name derived from the word *radius* ray. Chemically very closely resembles barium and it is, therefore, very hard to separate the salts of radium from those of barium. The most remarkable property of radium is its high radioactivity, several million times that of uranium. Radium emits alpha, beta and gamma rays. The salts of radium are luminous; the rays it emits, in addition to acting on photo-plates, produce many chemical reactions, destroy animal organisms and kill bacteria. The ability of radium incessantly to liberate large amounts of energy is particularly astounding. Its half-life is 1,580 years. Used in medicine for treating cancer and lupus.

Radioactive elements. Chemical elements continuously emitting invisible rays which like X-rays permeate through various substances, make the air electroconductive and blacken photo-plates, etc., are called radioactive. Rays emitted by radioactive elements are divided into alpha rays, beta rays and gamma rays. Potassium isotope with an atomic weight of 40, one of the isotopes of rubidium, indium, lanthanum, samarium, and rhenium, uranium, thorium, polonium, radium, protactinium and all transuranium elements have radioactive properties.

Radon (Rn). Atomic number – 86; atomic weight 222.0. Heaviest noble gas; product of radioactive transformation of radium. Short-lived: its half-life is 3.85 days; transformed into helium and solid substance radium A. Discovered by Dorn in 1900. The name stems from the same root as the word *radium*. Was also called radium emanation and niton. Used in treating cancer.

Rare earths (TR). Box 57 of Mendeleyev's Periodic Table contains not one element, as do the other boxes, but 15 closely related elements. Their atomic numbers run from 57 to 71. These elements are united under the general title of rare earths or "rare-earth" elements or, finally, lanthanoids (lanthanides). The rare earths include lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium and lutecium. Yttrium (No. 39) is also considered one of the rare-earth elements. Two groups of rare earths are distinguished: yttrian and cerian. All the rare earths are very much alike in their properties. In their free state these metals have very high melting points; they decompose water at ordinary temperature. In nature they are always encountered mixed with each other. It is very difficult to divide the rare earths. Monazite is the main rare-earth containing mineral. Only cerium has so far acquired practical importance. The history of the discovery of individual representatives of the rare earths is rather complicated. The existence of a "new earth" was first established by Gadolin in 1794; the last of the rare earths to be discovered was lutecium; promethium (No. 61) was artificially produced recently. Additional information on the individual elements of the rare-earth group will be found under their names.

Rhenium (Re). Atomic number – 75; atomic weight – 186.31. One of the most dispersed elements discovered by M. and Mme. Noddack only in 1925. Named after the Rhine River. Its properties had been predicted by D. Mendeleyev, who named it dvimanganese. In external appearance metallic rhenium resembles platinum. It is one of the heaviest and most refractory elements. The metal is particularly valuable for the electrical industry because it is used in the manufacture of filaments for electric bulbs which are more durable than tungsten filaments. It is also used in alloys. Occurs in the mineral molybdenite in amounts which do not exceed 0.00001 per cent.

Rhodium (Rh). Atomic number — 45; atomic weight — 102.91. Element of the platinum group. Discovered in 1804 by Wollaston; name derived from the Greek word *rhodon* — pink because of the colour of its salts. Occurs native together with the platinum elements. An alloy of platinum and rhodium is used in the manufacture of instruments for measuring high temperatures (thermocouples).

Rubidium (Rb). Atomic number — 37; atomic weight — 85.48. Element of the alkali group. Discovered by Bunsen in 1861 by spectral analysis. Named after the characteristic red lines of the spectrum (*rubidus* — dark-red). In its properties it is very close to sodium and potassium. Specific gravity — 1.52; melts at 39° C.; boils at 696° C. Occurs in extremely dispersed state; the largest amounts (up to 0.1 per cent) are found in amazonite (green feldspar); appreciable quantities of it are found in the mineral carnallite. Rubidium is radioactive; it emits only beta rays and is transformed into strontium. Its half-life is 70,000 million years.

Ruthenium (Ru). Atomic number — 44; atomic weight — 101.7. Platinum element. Discovered in 1844 by the Russian scientist Klaus in the city of Kazan and named in honour of Russia (Ruthenia in Latin means Russia). Brittle. Specific gravity — 12.26; melts at 1,950° C. Occurs together with other elements of the platinum group. It is extremely rare and has therefore found no application.

Samarium (Sm). Atomic number — 62; atomic weight — 150.43. Rare-earth element. Discovered by Lecoq de Boisbaudran in 1879 and named after the mineral samarskite. It colours the flame of the voltaic arc a pink-red. It is radioactive; emits only alpha rays and is transformed into neodymium.

Scandium (Sc). Atomic number — 21; atomic weight — 44.96. One of the most dispersed elements. Its existence was assumed by D. Mendeleyev in 1871. Discovered by Nilson in 1879 by spectral analysis. Its properties are not very well known. Named after the Scandinavian Peninsula.

Selenium (Se). Atomic number — 34; atomic weight — 78.96. Discovered by Berzelius in 1817; name derived from the Greek word *selene* — moon. Conducts electric current, its resistance varying with degree of illumination. The use of selenium in photoelectric cells is based mainly on this property. In chemical properties it is close to sulphur and, especially, to tellurium. Specific gravity — 4.8; melts at 217° C.; boils at 688° C. Found in a dispersed state as a small admixture in sulphur. In addition to photo-cells, selenium is used in electrical engineering, in the rubber and glass industries and in television. However, its uses are extremely limited.

Silicon (Si). Atomic number — 14; atomic weight — 28.06. Second most abundant element (after oxygen). Never occurs native, but in combination with oxygen (known as silica — SiO_2) or salts of silicic acid (silicates). Quartz and its numerous varieties are composed of silica. The most important technical products, such as glass, porcelain, cement and brick, like the main rocks — granite, basalt, syenite, etc., consist, primarily, of silicates. Discovered by Gay-Lussac and Thenard in 1810, but its nature as an element was established by Berzelius only in 1825. The name comes from the word *silex* meaning stone.

Silver (Ag). Atomic number 47; atomic weight 107.88. Noble metal. Known since early antiquity. Pure silver is white, very soft and ductile. Specific gravity — 10.5; melts at 960.5 C.; in its properties resembles gold and copper; does not change in the air and is very malleable. Best conductor of heat and electricity. Occurs native and in combination with sulphur and chlorine. Silver alloys serve for the manufacture of housewares, jewelry and silver coins. The Latin name (argentum) stems from the Sanskrit word *argenos* clear.

Sodium (Na). Atomic number — 11; atomic weight 22.997. Silvery-white metal, as soft as wax; oxidizes in the air (is kept in kerosene) and is lighter than water (specific gravity — 0.971). Discovered by Davy in 1807 by electrolysis of caustic soda; Davy's experiments were successfully repeated in Petersburg by the Russian chemist Semyon Vlasov. Latin name (natrium) derived from the Arabic word *natron* meaning soda, alkali. English name derived from "soda." Abundant in nature in the form of silicates and halides. Sodium and its salts are widely used in industry (common salt, soda, Glauber's salt, etc.).

Strontium (Sr). Atomic number — 38; atomic weight — 87.63. Belongs to alkaline-earth metals. Discovered in 1790 by Crawford. Metallic strontium is silvery-white, very active chemically and is, therefore, encountered only in combination. Colours the test flame red. Used in pyrotechnics and in the sugar industry.

Sulphur (S). Atomic number — 16; atomic weight — 32.066. Known since hoary antiquity. Has several varieties: rhombic, monoclinic and amorphic. The crystals of sulphur are light yellow. Very abundant in nature both in its native state and in the form of sulphide ores and sulphates (gypsum, anhydrite, etc.). Used for production of sulphuric acid, in destroying agricultural pests (phylloxera) and in the rubber industry. Constituent of hunters' powder, matches, Bengal lights, ultramarine (blue dye). Also used in medicine.

Tantalum (Ta). Atomic number — 73; atomic weight — 180.95. Rare element. Discovered in 1802 by Ekeberg and named in honour of the Greek mythical hero Tantalus. Easily machined and known for its extraordinary resistance to various chemical influences. This property is utilized in the manufacture of various important chemical apparatus and surgical instruments. The alloys of tantalum and carbon are noted for their extreme hardness which makes them very valuable in the manufacture of cutting tools and drills. Occurs always together with niobium and frequently with titanium.

Technetium (Tc). Atomic number — 43; the first chemical element produced artificially. Synthesized by K. Perrier and E. Segrè in 1937 by bombardment of molybdenum with the nuclei of the heavy isotope of hydrogen — deuterons. 17 of its isotopes are known today. The longest-lived isotope is the one with an atomic weight of 99. Chemically akin to rhenium and manganese. Name stems from the Greek word *technetos* — artificial, to mark the fact that it was the first artificially produced element. Its properties exactly coincide with those predicted by D. Mendeleyev, who had named this element ekamanganese.

Tellurium (Te). Atomic number — 52; atomic weight — 127.61. Discovered in 1782 by F. Müller; Klaproth confirmed this discovery in 1789 and gave the element its name from the Latin word *telluris* — earth. Chemically resembles sulphur and, especially, selenium. Finds limited use in the ceramics industry, in colouring glass and as an addition to gasoline in order to accelerate combustion in the engines.

Terbium (Tb). Atomic number — 65; atomic weight 159.2. Rare-earth element. Discovered by Mosander in 1843. Named after a small town Ytterby near which the rare-earth minerals were found for the first time.

Thallium (Tl). Atomic number — 81; atomic weight — 204.39. Discovered by Crookes in 1861 by spectral analysis. Name derived from the Greek word *thallos* green twig because of the green colour of its spectral lines. Metal lighter than lead and very volatile; melts at 302° C. and colours the test flame green. Encountered in a dispersed state. The principal raw material is the dust produced during the annealing of the sulphide ores of certain metals. Used as a constituent in acidproof alloys, in the manufacture of optical glass and in photocells.

Thorium (Th). Atomic number — 90; atomic weight 232.12. One of the most important radioactive elements. Discovered by Berzelius in 1828 and named after Thor, the Scandinavian god of war. Radioactivity of thorium was established in 1898 by Curie-Sklodowska and Schmidt. In its free state it is a metal; specific gravity — 11.7; melts at 1,842° C. Externally resembles platinum. Its half-life is 13,000 million years. In disintegrating thorium forms the thorium series of radioactive elements, the last member of which is lead with an atomic weight of 208. Monazite and thorite are thorium's chief minerals. Monazite is extracted from monazite-containing sands. Thorium oxide is very important for incandescent gas mantles. Like uranium thorium splits and liberates a large quantity of atomic energy.

Thulium (Tu). Atomic number — 69; atomic weight 169.4. Rare-earth element. Discovered by Cleve in 1880; name derived from the word *Thulia*, the ancient name of Scandinavia. The salts of thulium are green.

Tin (Sn). Atomic number — 50; atomic weight 118.70. One of the first metals known to man since early antiquity (bronze age). In its free state quite a malleable and ductile silvery-white metal; specific gravity 7.28; melts at 232° C. Below 18° C. changes to its grey variety. When short sticks of tin are bent they produce a characteristic crackle probably because of the friction of the individual crystals against each other. Unaffected by water and air; owing to this property it is widely used for plating iron (so-called white metal utilized chiefly for food cans). Its alloys — babbit and bronze — are very important. Encountered mainly as the mineral cassiterite (SnO_2).

Titanium (Ti). Atomic number — 22; atomic weight 47.90. Silvery-white, very hard and brittle metal. Very abundant element; constitutes 0.6 per cent of the weight of the earth's crust. Discovered by Klaproth in 1795, but produced in its pure state only in 1857 by Wöhler and Sainte-Claire Deville and named in honour of the mythological hero. Specific gravity — 4.5; melts at 1,800° C. Practical importance of titanium is especially great in metallurgy; aids in completely removing oxygen and nitrogen from molten steel due to which the smelting is remarkably uniform; imparts hardness and elasticity to steel. Metallic titanium is stable in sharp temperature variations and may be extensively used in high-speed aviation. Titanium oxide serves for the manufacture of very good white paint.

Transuranium elements. Radioactive elements following uranium in Mendeleyev's periodic system with atomic numbers of 93 and up. Have all been obtained artificially. The first to be studied was neptunium (in 1939). Since their lifespan is much briefer than the age of our planet they were not discovered under natural conditions. The transuranium elements known today are: neptunium, plutonium, americium, curium, berkelium, californium, einsteinium, fermium and mendelevium.

Tungsten (W). Atomic number—74; atomic weight—183.92. Heavy (specific gravity—19.1), silvery-white metal with a high melting point (3,370° C.). Discovered by Scheele in wolframite in 1783; obtained in its pure state by Wöhler only in 1850; does not oxidize and does not dissolve in acids with the exception of aqua regia; refractory; because of the ability of tungsten to be drawn into wire down to 0.01 mm. thick it is used in the manufacture of filaments for electric bulbs; also used in high-speed steel and super-hard alloys which are called pobedite, "Wie Diamant" and carboloy, in the manufacture of chemical laboratory-ware and for contacts as a substitute for the more expensive platinum. Pobedite is almost as hard as diamond and is used for drilling the hardest rocks.

Uranium (U). Atomic number—92; atomic weight—238.07. Refractory, silvery-white metal. Only recently occupied the last place in the periodic table of elements. Discovered in pitch-blende by Klaproth in 1789, but produced in its pure state by Péligoth in 1841. Specific gravity—18.7; melts at 1,690° C.; radioactive. While studying uranium Becquerel discovered the phenomenon of radioactivity in 1898. Native uranium has several isotopes. The isotope with an atomic weight of 238 prevails; there is 0.7 per cent of the isotope with an atomic weight of 235. Because of its radioactive disintegration uranium 238 forms elements of the uranium series while uranium 235 forms the actinium series. The end product of the uranium series is lead with an atomic weight of 206; that of the actinium series is lead with an atomic weight of 207. Uranium 235, when its nucleus is bombarded by slow neutrons, is easily split into two nearly equal fragments liberating an enormous quantity of atomic energy. Named after the planet Uranus, discovered shortly before the discovery of this element.

Vanadium (V). Atomic number—23; atomic weight—50.95. Steel-grey metal, very hard, but not brittle. Discovered in 1830 by Sefström and named in honour of the goddess Vanadis. It is quite abundant but found only in a dispersed state; produced from titanomagnetite ores and from bituminous shales; used mainly in the production of high-grade steel distinguished for its durability, resilience and tensile strength; also used as a catalyst in the chemical industry, as a dye in ceramics, for toning prints in photography, and in medicine.

Virginium. Under this name Allison described an element with the atomic number of 87. The fact of the discovery was not confirmed. See *Francium.*

Xenon (Xe). Atomic number—54; atomic weight—131.3. Noble gas discovered by Ramsay and Travers in 1898 at the same time as krypton and neon. Name comes from the Greek word *xenos*, meaning alien. Occurs as a negligible constituent of the air. It is 4.5 times as heavy as air.

Ytterbium (Yb). Atomic number—70; atomic weight—173.04. Rare-earth element. Discovered in 1878 by Marignac who established that the element erbium contained a "new earth." The name comes from the small Swedish town of Ytterby.

Yttrium (Y). Atomic number—39; atomic weight—88.92. Very close to the lanthanoid family in properties and owing to common occurrence with them in nature is considered one of the rare earths. Occurs in large quantities in the minerals xenotime and gadolinite. Discovered by Gadolin in 1794 and first obtained in its pure state by Wöhler in 1828. Thus far its practical uses have been rather insignificant.

Zinc (Zn). Atomic number—30; atomic weight—65.38. Discovered by Paracelsus in the 16th century. Received its name from the Greek word *zinko* meaning white film (the salts of zinc are white). Metallic zinc is greyish-white and rather stable against the action of water and air. Occurs mainly in the mineral sphalerite (ZnS). Used in iron-plating (galvanized iron), and in alloys with copper (brass). The white salts of zinc are used as a paint as well as in medicine.

Zirconium (Zr). Atomic number—40; atomic weight—91.22. Discovered by Klaproth in 1789 and named after the mineral zircon. Zirconium oxide is very refractory; melts at 3,000 C.; extraordinarily stable against chemical action. Because of these properties it is used as a highly refractory material. Also used as an addition to pig iron because it improves its casting properties. Occurs in zircon and complex silicates.

GLOSSARY

Abrasives or *abrasive materials*—very hard substances which, when pulverized, yield sharp-edged grains. Abrasives are used for cutting, sawing, drilling, sharpening, grinding, polishing and other types of machining metals, stones, glass, etc. The most important *natural* abrasives are: diamond, corundum, garnet, flint, quartz, sandstone and pumice; *artificial*: synthetic corundum (electrocorundum and alundum); carborundum (alloys of quartz and carbon); stalinite, wolomite (alloys of tungsten and carbon) and boron carbide. The technical importance of abrasives is enormous.

Acetylene—gas resulting from the action of water on calcium carbide. Burns with a bright white flame: widely used in oxygenous cutting, gas-welding of ferrous and non-ferrous metals and in soldering.

Adit—horizontal or slightly inclined mine working with one end coming out to the surface. Cross section of an adit is trapezoidal, oval or round.

Agate—striped stratified chalcedony with layers of different colours (white, red, black, etc.). See *chalcedony*.

Agricola—Latinized name of Georg Bauer (1494-1555), German physician, mineralogist and metallurgist. His work *On Mining* served as an aid in the techniques of mining and metallurgy for a period of two centuries.

Alaite—very rare, beautiful red mineral; natural vanadic acid ($V_2O_5 \cdot H_2O$). Found in Central Asia.

Alchemy—medieval name of chemistry. The pre-scientific period in the development of chemistry is usually referred to as alchemy.

Alpha rays. See *alpha particles*.

Alpha particles—helium ions emitted by some radioactive substances. On passing through a substance the alpha particles ionize it; on striking fluorescent or phosphorescent substances they cause them to luminesce. Upon contact with human or animal skin they produce burns which are hard to heal. Also able to provoke certain chemical reactions.

Alumina—aluminium oxide (Al_2O_3). Forms part of many rocks and minerals (alumosilicates). Technically obtained mainly from bauxite. Occurs native as corundum, etc.

Alumosilicates—silicates in which aluminium oxide, i.e., alumina, plays an essential part.

Alums—chemical compounds representing double salts of sulphuric acid. In nature most frequently encountered in the form of aluminium (alunite) and ferric (halotrichite) alums.

Alundum—alumina (Al_2O_3). Produced artificially from natural alumosilicates or bauxites. See *abrasive materials*.

Alunite or alum rock—white or red-brown mineral, natural sulphate of potassium and aluminium.

Amber—fossilized tar of coniferous trees mainly of the Tertiary Period, hardened into dense mass. Colours ranging from milky, honey-yellow and brown to dark-orange and reddish. Brittle, but easily ground and polished. Burns with aromatic odour. Used in the chemical industry, in electrical engineering and for manufacture of various articles.

Amethyst—transparent, violet-coloured mineral; variety of quartz. See *quartz*.

Ampangabeite—rare, brown-red, radioactive mineral; tantalo-niobate of uranium, iron, etc. First found on Madagascar.

Amphibole or *horn-blende*—dark-green, greenish-black or black-brown mineral with glassy lustre. A rock-forming mineral of the silicate class. Encountered in continuous granular and fibrous masses.

Angström—unit of length corresponding to 0.00000001 cm, or 10^{-8} cm. Designated by Å. Used mainly in optics to measure the length of light-waves and in atomic physics. Named after the Swedish scientist Angström who was the first to introduce this value into practice in 1868.

Aneroid. See *barometer*.

Anion. See *ion*.

Antimonite, *antimony glance* or *stibnite*—native antimony trisulphide Sb_2S_3, lead-grey mineral with metallic lustre, frequently with a parti-coloured oxide tint. Encountered in needle-shaped crystals and in dense masses. Used for production of antimony.

Anthracite—grade of coal characterized by highest carbon content (up to 96 per cent).

Antimony glance. See *antimonite*.

Apatite—mineral; calcium phosphate containing fluorine and chlorine. Used for production of phosphatic fertilizer.

Aquamarine—transparent variety of beryl coloured blue-green shades of sea-water (from the Latin words: *aqua* water, *mare* sea); valued as a precious stone.

Aragonite—mineral corresponding to calcite ($CaCO_3$) in composition, but differing from it by the arrangement of its atoms and by its physical properties. Colour—white, yellow, green or violet. Dense formations in the shape of spherical oolites, as well as many stalactites and stalagmites found in caves, are characteristic of aragonite. Usually formed from hot and cold waters.

Argonauts—seafarers on the ship *Argo*, heroes from the ancient Greek legends who sailed to Kolchis (now Transcaucasus) under the leadership of Jason in quest of the golden fleece. The myth about the Argonauts is a reflection of the history of early Greek colonization (8th-6th centuries B. C.).

Aristotle (384-322 B.C.)—great ancient Greek philosopher. Aristotle's works covered all branches of knowledge of his time: logic, psychology, natural science, history, politics, ethics and esthetics. None of his works have survived; only separate excerpts cited by ancient authors are known.

Asbestos—group name of a number of fine-fibre minerals, magnesium silicates. The fibres reach 5 and more cm. in length. Asbestos is used for production of fireproof fabrics, for thermal and electric insulation, for valuable fireproof materials, etc.

Astrophysics—branch of astronomy studying the physical state and chemical composition of celestial bodies and interstellar matter.

Asphalt—hard brownish or lustreless black bitumen, frequently merely hardened oxidized oil. Softens at 70 to 110° C. and then melts. There are native and artificial asphalts.

Atmosphere—gaseous shell of the earth. Three layers are now distinguished in the atmosphere: 1) troposphere, 2) stratosphere and 3) ionosphere.

Atoll—coral-island in the form of a continuous or broken ring surrounding a lagoon. Encountered in the open sea, arranged singly or in archipelagoes.

Atom (from the Greek word meaning *indivisible*)—minutest particle of a chemical element. Until the middle of the 19th century the atom was believed to be an absolutely indivisible and invariable particle of substance. In the beginning of the 20th century it was demonstrated that the atom was indivisible only chemically.

Aztecs—one of the prominent Indian peoples in Mexico. The conquest of Mexico by the Spaniards in 1519-21 terminated the independent development of this people.

Baikalite—dark, dull-green variety of a lime-ferruginous silicate, diopside from Lake Baikal.

Barite or *heavy spar*—heavy, opaque mineral ($BaSO_4$), barium sulphate. Colourless, or more frequently coloured yellow, red, bluish and other tints. Widely used in the manufacture of white paints, chemical preparations, etc.

Barometer (from the Greek words *baros*—gravity and *metreo*—I measure)—meteorological instrument used in measuring atmospheric pressure.

There are mercury and metal (*aneroid*) barometers.

Basalt—black or black-green igneous rock poured out to the earth's surface or under water in a molten state. Consists of minerals rich in magnesium and iron. Forms separate hexagonal columnar structures.

Basaltic bed—according to certain modern petrographers basalts are the initial maternal magma which forms a basaltic shell that underlies the hard earth's crust.

Bauxite—white, sometimes reddish, argillaceous rock consisting of hydrous compounds of alumina, oxides of iron and titanium. Serves as a raw material for the production of aluminium.

Belomorite—moonstone from the pegmatite veins of White Sea regions; variety of albite (feldspar).

Bengal light—various slow-burning pyrotechnical compounds producing a bright white or coloured flame during combustion. Used in illuminations and fireworks. Colour depends on the chemical element used (for instance, strontium imparts a red colour, etc.).

Beryl—chief mineral for the production of metallic beryllium. Consists of silicon, aluminium and beryllium (up to 14 per cent of its oxide). Colourless or coloured greenish and yellowish tints. Encountered in the form of transparent, well-coloured varieties: emerald (bright green), aquamarine (the colour of sea-water), vorobievite (pinkish), etc. Pure and well-coloured beryl is a precious stone; emerald is particularly valuable.

Beryllium bronze—mixture of copper and beryllium (2 to 2.5 per cent Be); durable, resilient and good conductor of heat and electricity. Used in the manufacture of springs and important springy machine-parts, gears, cogwheels, bushings and bearings for service at high speeds, high pressures and high temperatures.

Berzelius Jöns Jakob (1779-1848)—famous Swedish chemist and mineralogist. Honorary member of the Petersburg Academy of Sciences. His textbook of chemistry and annual reviews of chemical progress (1820-47) disseminated chemical knowledge in the first half of the 19th century.

Beta rays—stream of electrons emitted during disintegration of atomic nuclei. Capable of ionizing gases, making many substances luminescent and acting on photoplates.

Biotite. See *mica*.

Bitumen—name of a mixture of various hydrocarbons encountered in nature in the form of gases (oil gases), liquids (oil and asphalt) and solid substances (ozocerite). Bitumens often impregnate various rocks: limestones, slates and sandstones: such impregnated rocks are called bituminous.

Bituminous coal—black mineral containing from 70 to 90 per cent carbon. See *Mineral coal*.

Bolide—fire-ball sweeping across the sky; caused by the invasion of a meteoric body from interplanetary space into the earth's atmosphere.

Borax or *tincal* ($Na_2B_4O_7 \cdot 10H_2O$)—sodium tetraborate. Easily dissolves metallic oxides and therefore serves for cleaning surfaces in soldering. Used in ceramics and leather-making, in medicine, etc.

Bore-hole—special pit characterized by round cross-section of a very small diameter and considerable length. Bored by means of a percussion or rotatory tool. Made to determine the extent and quality of mineral deposits, for extraction of oil, water, sulphur, etc. They reach a depth of more than 5,000 metres.

Boric acid (H_3BO_3)—weak acid. Encountered in the mineral *sassolite*. White scale-shaped crystals.

Boulders—fragments of rocks, mainly granites, quartzites, limestones and others, measuring from 10 cm. to 10 m. and more in diameter. Formed by weathering of rocks and by glacial activity. Used for paving streets and as a filler in concrete structures; large boulders are used for monument pedestals.

Boyle, Robert (1627-1694)—famous English chemist and physicist.

Bronze—nowadays an alloy of copper and various other elements, mainly metals. Only a few decades ago the term *bronze* designated alloys of copper and tin alone.

Brown coal—variety of mined coal. Contains 50 to 90 per cent carbon and in combustion yields quite a lot of ash and sulphur. Widely used as fuel.

Calcite or *limespar*—white, colourless or slightly coloured mineral—calcium carbonate ($CaCO_3$), frequently with various admixtures. Occurs in excellently formed crystals, granular and compact masses, stratified forms, in stalactites and stalagmites. The perfectly transparent calcite which doubles the image viewed through it is called *Iceland spar*. Some rocks consist entirely or almost entirely of calcite as, for example, marbles, limestones and chalk.

Calory—unit of heat. Large calory is the amount of heat required to raise the temperature of 1 kilogramme of water by 1° C.; small calory is the amount of heat required to raise the temperature of 1 gram of water by 1° C.

Carat—measure of weight of precious stones; equals 200 milligrams.

Carbides—chemical compounds of metals and carbon produced by the action of coal on metals or on their oxides.

Carbonates—salts of carbonic acid. Very abundant in nature.

Carlsbad stone—solid deposits of calcium carbonate from hot mineral springs in Karlovy Vary (Carlsbad) in Czechoslovakia. (See *aragonite*.)

Carnallite—transparent, reddish mineral; hydrous chloride of potassium and magnesium. Deliquesces in the air. Source of potassium fertilizer and of metallic magnesium.

Cassiterite or *tinstone* — mineral ranging in colour from brown to black; tin oxide (SnO_2) containing up to 79 per cent tin. Chief tin ore.

Cation. See *ion.*

Cat's eye — greenish transparent quartz shot with silk because of the inclusion of asbestos fibres. Its stripes play beautifully, especially when it is ground with cabochon.

Caves or cave phenomena — reliefs typical of terrains formed by rocks soluble in water and pervious to it — limestones, dolomites and gypsum. As a result of lixiviation of the rocks by underground water, craters and extensive closed hollows are formed on the surface and cavities and caves in the interior. In these regions rivers frequently flow into crevices and craters, run underground and then come out to the surface again. Cave phenomena are well developed in the Crimea, in the Urals and in some regions of Siberia.

Cavity — natural store-house in pegmatite veins. Beautifully formed crystals of various minerals frequently grow on the walls of these cavities.

Celestite — beautiful sky-blue mineral; strontium sulphate ($SrSO_4$). Used for production of strontium salts.

Cement — calcined mixture of limestone and clay. With water cement hardens into strong stony mass. Manufactured in enormous quantities and used for building purposes.

Ceramics (from the Greek word *ceramos* — clay) — articles made of baked clay and its compounds with mineral additions. Ceramic wares include building brick, tile, facing slabs, clinker, water and canalization mains, fire- and acid-proof articles, pottery, majolica, faience and porcelain. Ceramics began to be produced as primitive baked articles in the stone age.

Chalcedony — mineral of all possible colours, a latent-crystalline fibrous variety of quartz. Encountered in form of nodules and stalagmites. Semi-transparent and translucent. Used for technical wares, as a semi-precious stone and in the manufacture of various articles.

Its striped varieties are called *agates*.

Chalcopyrite — brass-yellow mineral containing 35 per cent copper, 35 per cent sulphur and 30 per cent iron. One of the main copper ores.

Chalk — white, soft, fine-earth sedimentary rock of organic origin. Formed by accumulation of microscopic shells and consists mainly of calcium carbonate.

Used in glass, cement, rubber, paper and paint industries, as writing material, etc.

Chlorites — minerals; hydrous alumosilicates of magnesium in which part of the magnesium oxide and alumina is replaced by iron oxides; colour — all shades of green to black; biotites, horn-blendes and pyroxenes most frequently change to chlorites. The mineral is lamellar like mica, but is non-resilient.

Chromite — heavy black or brown-black mineral. Encountered in dense and granular masses. Ore for the production of chromium.

Chrysoberyl — transparent green mineral containing beryllium and aluminium with an admixture of iron and sometimes chromium ($BeAl_4O_2$). Rare precious stone (*chrysos* — golden, *beryllos* — beryl).

Cinnabar — red mineral with adamantine lustre; mercuric sulphide. Chief mercury ore.

Clay — sedimentary rock consisting mainly of hydrous silicic compounds of aluminium and frequently containing minutest particles of various minerals; plastic and capable of forming a putty-like mass when mixed with water. Used in building, pottery, etc.

Cleopatra—last Queen of Egypt (69-30 B.C.).

Cleveite—mineral containing uranium and certain amount of rare earths. When heated liberates large amounts of helium included in the mineral as a result of radioactive disintegration of uranium. Scientists discovered the existence of helium on earth for the first time by studying the liberation of gas from cleveite. Until then helium was known to exist only in the sun.

Columbite—brown-black, opaque, rare mineral—tantalo-niobate of iron and manganese. Source of tantalum and niobium. Occurs mainly in pegmatite veins.

Concentrate—the valuable mineral separated from an ore undergoing a specific treatment.

Concentration preliminary processing of a mineral in order to separate it from valueless rocks (gangue) or other minerals.

Concrete—artificial rocky conglomerate material; hardened mixture of a binding agent (cement), water and natural or artificial rocky fillers (sand, fine slag, gravel and crushed stone).

Coral reefs—rocky underwater (or rising above the water) reefs formed mainly by lime structures of coral colonies. Abundant only in tropical seas near continental coasts and islands or in shallow sections of the open sea.

Corals—or coral polyps—marine animals, coelenterates. Live principally in colonies and lead a sedentary life. The skeleton is made of separate lime cells.

Corundum—mineral consisting of aluminium oxide (Al_2O_3). Exceptionally hard; scratches all minerals except diamonds. Its transparent uniformly coloured crystals are used as precious stones. Red corundum is known as *ruby*, the blue variety—as *sapphire*.

Cosmic speed—speed at which a celestial body moves through space; it is many times as high as the known speeds at which various bodies move on earth.

Cosmic rays—rays which penetrate into the atmosphere of the earth, carry enormous energy and, therefore, have high penetrating power. The nature of cosmic rays is not very well known as yet.

Cretaceous period—geological period terminating the mesozoic era in the formation of the earth's crust. Subdivided into two epochs—lower and upper cretaceous epochs. The marine sediments of this period are especially noted for deposits of powerful layers of writing chalk.

Crocus—natural or artificial abrasive material; used in polishing metals, optical and other glass, building and decorative stone.

Cryolite—very rare snow-white mineral—aluminium and sodium fluoride (Na_3AlF_6). In the molten state it dissolves aluminium oxide, therefore it is used in electrolysis of metallic aluminium, as well as in production of glass and faience. It is now manufactured artificially.

Crystal—geometrically regular structure of atoms or ions located in the points of a crystal lattice. The word *crystal* was used long before our era and meant rock crystal whose origin was then connected with petrified ice. Subsequently this word began to be used to signify all minerals of a natural polyhedral form. Crystals are studied by crystallography.

Crystallography—science about crystals; studies their shapes, optical, electrical, mechanical and other properties, as well as problems connected with the origin and growth of crystals and their dependence on differences in chemical composition.

Curie-Sklodowska, Marie (1867-1934)—outstanding scientist, one of the founders of the theory of radioactive substances. First woman professor at Sorbonne (France). Discovered polonium and radium (1896).

Cyaniding—method of extracting gold from rocks. By this method finely-dispersed gold is dissolved in aqueous solutions of potassium cyanide.

Darwin, Charles Robert (1809-1882)—great English naturalist, creator of the materialist theory of historical development of living nature—Darwinism. Founder of scientific evolutionary biology. Author of the *Origin of Species* and other books. His historic contribution was that his theory helped in the victory of materialism over idealism in cognition of living nature.

Democritus (about 460-370 B.C.)—great Greek materialist philosopher.

Deoxidizers—materials added to liquid steel after the admixtures have burned out in order to reduce the amount of ferrous oxide dissolved in the metal, this being necessary because ferrous oxide causes red shortness. Deoxidizers usually contain three elements that reduce the ferrous oxide—carbon, manganese and silicon.

Deuterium (from the Greek word meaning "second")—heavy isotope of hydrogen H_2. The mass of the deuterium atom is about twice that of the atom of usual hydrogen and equals 2.01471. With oxygen forms heavy water D_2O and peroxide D_2O_2, which is more stable than hydrogen peroxide. Discovered in 1932.

Diamond—crystalline variety of carbon. The hardest of all known minerals in nature. Colourless or slightly coloured; rarely black. Fine precious and technical stone. Formed from molten rocks at high pressures and temperature.

Diatomaceous seaweeds (diatomeae) or silicious seaweeds—microscopic unicellular seaweeds with armour (tunic) impregnated with silica. Abundant in fresh and sea-waters throughout the world. Rock-forming organisms: form thick deposits of diatomite (diatomaceous sediments) and kieselguhr (infusorian earth). These accumulations—*diatomites* and kieselguhr—are of great economic importance as building materials and abrasives.

Diorite—igneous greenish-grey rock. Consists of plagioclase and horn-blende, sometimes with biotite and quartz (quartz diorite). Its great toughness and hardness make it a good building material.

Disthene—mineral. See *kyanite*.

Dokuchayev, Vasily (1846-1903)—great Russian naturalist, founder of modern soil science and complex nature studies. Dokuchayev's methods have formed the basis of scientific geography. *Russian Chernozem* (1883) is his classical work.

Dolomite—white, grey, or slightly coloured mineral; calcium and magnesium carbonate. Contains 54 per cent CaO and 44 per cent MgO.

The term dolomite also signifies a dense sedimentary rock composed mainly of grains of the mineral dolomite. Occurs in marine deposits of different geological periods. Used as fireproof material, as flux in blast-furnace smelting, in the chemical industry and in building.

Earth's crust (*lithosphere*)—the outer hard shell of the crust which is theoretically supposed to be only 15 to 17 kilometres thick (from the surface).

Some scientists believe it to be as much as 60 kilometres thick.

Electron—elementary particle carrying charge of negative electricity. Component part of atom. In the atom electrons revolve along definite orbits around the positively charged atomic nucleus. The number of electrons in an atom corresponds to the atomic number of the chemical element.

Electronic microscope—up-to-date microscope using a stream of electrons instead of a ray of light making it possible to magnify the object up to a million times.

Electroscope—instrument for detecting or roughly measuring the electric tension between two bodies.

Emanation—gaseous products of disintegration of radioactive elements.

Emerald. See *beryl*.

Euclase—very rare, transparent, blue or bluish-green mineral of the silicate group; very close to beryl. Beautiful precious stone.

Face—wall of a stope being worked upon.

Fans—long and gently-sloping deposits of rocks washed and transported by water and carried out to plains.

Feldspar—most abundant group of minerals constituting about 50 per cent by weight of the entire earth's crust; chief constituent of most rocks; aluminium silicates of sodium, potassium and calcium. Depending on composition divided into 1) potassium feldspars (*orthoclase* and *microline*) and 2) sodium-calcium feldspars (*plagioclases*).

Fluorescence—luminescence of a substance which is not due to heating, but to irradiation of its surface by solar rays, light of the voltaic arc, ultra-violet or X-rays. Luminescence ceases immediately upon removal of the influence.

Fluor spar. See *fluorite*.

Fluorite or *fluor-spar* mineral transparent to opaque; most frequently coloured various shades of violet, green, blue and grey, with glassy lustre; chemically calcium fluoride. Used in metallurgy as flux which lowers the temperature of metal smelting, in the chemical industry—for production of hydrofluoric acid, for impregnating sleepers, in ceramics and in glass manufacture. Transparent crystals are used in optics and are known as optical fluorite. More beautiful samples are used in the manufacture of various articles. The earthy pink-violet variety of fluorite is called *ratovkite*.

Flux—mineral substances added to ore to facilitate smelting of the latter and to separate the metal from the molten gangue (slag). Quartz, limestone, fluorite and other minerals and rocks may serve as fluxes.

Foraminifera—unicellular protozoa with a shell made up in most cases of calcium carbonate ($CaCO_3$); occur in marine sedimentary deposits of all geological periods; some foraminifera are important for estimating the geological age of rocks.

Fulgurites—small tubes, the thickness of a finger, burned out or caked in sand by an electric discharge in the form of lightning.

Gabbro—Plutonic magmatic rock. Rich in iron, calcium and magnesium and poor in silicious acid. Black, greenish or grey. Excellent building material.

Gadolinite—black or greenish-black rare mineral; complex silicate of rare-earth elements.

Galaxy or galactic system—accumulation of stellar systems composed of many thousands of red-hot stars. Our sun, for example, belongs to the Milky Way Galaxy, where it forms only one of the luminescent stars among tens of thousands of others.

Galena, or *lead glance*—grey mineral with silver lustre (PbS) containing up to 86 per cent lead. Contains silver as a constant admixture and is frequently a valuable silver ore. Used for the manufacture of red lead, production of lead, white lead and glazing; also used in radio-engineering.

Galvanometer—highly sensitive electric measuring instrument.

Gamma rays—electromagnetic emanation with very short waves. Arise during disintegration of the atoms of radium and other radioactive substances. Resemble X-rays, but have greater penetrating power.

Garnets—very abundant group of hard minerals including many varieties (class of silicates) of different colours with a pronounced glassy lustre. Certain garnets are used as decorations as well as abrasive material.

Gedroits, Konstantin (1872-1932)—Soviet soil scientist and agrochemist; academician since 1929. Founder of the theory of soil colloids and their role in the formation of the soil and in its fertility.

Geode—round, oval and more rarely, lentil-shaped cavities in rock; minerals crystallize on their walls.

Genesis—origin. In mineralogy the theory of genesis (origin of minerals) aims at finding the way and conditions under which minerals are formed and at studying their subsequent changes.

Geological era—largest time unit in geological chronology corresponding to a geological group. Four eras are distinguished: Archaic, Paleozoic, Mesozoic and Cainozoic.

Geophysics—complex of sciences about the physical properties of the earth and of the physical processes occurring in it.

Glacier—natural mass of ice flowing like an ice-river slowly down the slope of a mountain or down a valley by gravity. In its movement the glacier destroys its bed, polishes the projections in its bed, scratches them with fragments of rock frozen into the ice, transports them over considerable distances and deposits tremendous quantities of rock fragments, rounded boulders (moraines), etc. Upon reaching the region of melting the mountain glacier gives rise to rapid rivers.

Gneiss—metamorphic schistous rock. Akin to granite in composition. Used as building material.

Goethite—yellow-reddish or black-brown brittle mineral; hydrous iron oxide. Used as an iron ore along with other iron oxides.

Golitsyn, Boris (1862-1916)—Russian physicist, academician; founder of seismology and author of numerous scientific papers.

Granite—igneous rock of crystalline-granular structure. Consists of quartz, feldspar, mica and sometimes of horn-blende. Has different colours from white to black or from light pink to dark red. Because of its strength, beauty and the ability to produce large monoliths, it is a very valuable building, facing, sculptural and acid-resistant material.

Graphite—soft, oily to the touch and soiling mineral; variety of crystalline carbon ranging in colour from black to steel-grey. Melts above 3,000° C.; acid- and alkali-resistant. Used in the foundry for the manufacture of crucibles, electrodes, dry cells, and for paints, pencils, etc.

Grey copper ores—name of a group of minerals whose chief representatives are *tennantite* or copper arsenide and *tetrahedrite* or copper antimonide. Tetrahedrites are used along with other minerals in smelting copper.

Gypsum—mineral and monomineral sedimentary white or slightly coloured rock ($CaSO_4 \cdot 2H_2O$). Very abundant in nature and widely used for building, decorative and plastic work and for manufacture of cement; also used in medicine for surgical casts and in agronomy for improving the soils. Alabaster and selenite are varieties of gypsum.

Half-life—the time required for half the initial number of atoms of radioactive elements to disintegrate. Each radioactive element has its own constant half-life period. These periods range from a fraction of a second to thousands of millions of years.

Halite (or common salt—rock salt—NaCl (sodium 39.39 per cent, chlorine—60.61 per cent). Salty to the taste. The name "halite" is connected with the Greek word *halos* meaning salt. Since it is used in the food, it has been given the name of common salt. Deliquescence in humid air is due to the presence of admixtures.

Rock salt was formed in the past geological periods on the floors of former water basins. This salt is now found in massive form among rocks. In addition, salt is also deposited on the surface of the earth, mainly in steppe and desert regions, in the form of films, so-called efflorescences.

Heraclitus of Ephesus (about 530-470 B.C.)—outstanding ancient Greek materialist philosopher. His philosophy was exhaustively and scientifically analyzed in the works of the classics of Marxism-Leninism.

Herodotus (about 484-425 B.C.)—ancient Greek historian known as the Father of History. Author of the unfinished *History of Greco-Persian Wars.*

Hershel, John (1792-1871)—English astronomer, son of William Hershel, outstanding English astronomer.

Homer—legendary epic poet of ancient Greece.

Horn-blende. See *amphibole.*

Humboldt, Alexander Friedrich Wilhelm (1769-1859)—outstanding German naturalist and traveller.

Humic acids—acid part of humin substances constituting the natural humus of the soil. These complex organic substances play an important part in plant growth.

Iceland spar. See *calcite.*

Igneous rocks. See *magmatic rocks.*

Ilmenite or ferrous titanate—black, opaque, semi-metallic mineral ($FeTiO_3$). Important ore for titanium production.

Ion—atom, molecule, part of molecule or group of molecules carrying a positive or negative electric charge. In electrolysis positively-charged ions move towards the cathode and are called *cations* (for example, the metal in a salt, the hydrogen in an acid), while ions, charged negatively, move towards the anode and are known as *anions.* The mutual attraction of the ions with opposite charges is the reason they combine into molecules.

Ionization—transformation of neutral particles (molecules, atoms) in any medium into particles carrying a positive or negative electric charge, i.e., into ions.

Iron ores—mineral substances containing from 25 to 70 per cent iron. Include various compounds of iron and oxygen: hematite, magnetite, brown hematite and its varieties (limonite, limnite, hydrogoethite, etc.), goethite, siderite (iron spar), ferruginous quartzite, etc. Compounds of iron and sulphur are not fit for production of the metal.

Isotopes—varieties of chemical elements with different atomic weights, differing in mass numbers from the atoms but having the same nuclear charge and, therefore, occupying the same place in Mendeleyev's periodic system.

Jasper—variety of chalcedony with extensive mixtures in the form of a finely-dispersed dye. Encountered in large concentrations. The durability and hardness of jasper, the beauty and variety of its shades make this stone technically and artistically valuable.

Joliot-Curie, Frédéric (born in 1900) — outstanding French physicist, one of the most prominent scientists in the field of nuclear physics, eminent progressive public figure and winner of the International Lenin Prize *For Strengthening Peace among the Nations*. Chairman of the Peace Council. Member of the Communist Party since 1942.

Kaolin porcelain clay; name derived from the Chinese word *kaolong* (mountain with kaolin deposits): light-coloured, more frequently light, loose, fine-grained clay consisting almost entirely of the mineral *kaolinite*. Pure kaolin is highly fireproof and melts at 1,750° C. Formed by decomposition of rocks rich in feldspar. Used in faience-porcelain, paper, rubber, chemical and other branches of industry.

Kaolinite opaque, lustreless white mineral $Al_2(OH)_4(Si_2O_5)$. Contains about 40 per cent alumina (aluminium oxide), silica and water.

Kimberlite -dark, almost black magmatic rock, consisting mainly of olivine, brown mica and pyroxene which hardened in large explosion craters; in South Africa and in America it contains crystals of diamond.

Kunzite transparent, light-lilac or pink variety of the mineral called spodumene, a silicate of lithium and aluminium. Used as a precious stone.

Kursk magnetic anomaly vast territory near the city of Kursk where a considerable deviation of the magnetic needle is observed; the deviation is caused by large magnetite deposits.

Kyanite or *disthene* —mineral of beautiful blue shades, nearly transparent. Contains about 60 per cent aluminium oxide. Used as a highly fire- and acid-proof material, while the transparent and beautifully coloured varieties of kyanite are faceted.

Labrador - bluish-grey or black iridescent (resembling a peacock feather) mineral of the feldspar group.

Labradorite —mixed crystalline rocks consisting chiefly of labrador. Fine building and decorative stone.

Laccolith - shape in which magmatic rocks are deposited in the earth's crust, i.e., flat-convex bodies resembling a loaf of bread or the cap of a mushroom. Magma hardened before reaching the earth's surface and arched the overlying layers. Freed by weathering and erosion of the overlying sedimentary rocks it forms low mountains, for example, Beshtau and Mashuk (North Caucasus), Ayu-Dag (the Crimea), etc.

Lagoon shallow gulf or bay separated from the sea (or lake) by alluvial sand or clay. Depending on the climate of the region the lagoon may have salty or saltish water; the salinity of the water is sometimes due to the fact that sea-water periodically breaks into the lagoons. Organic world of the lagoons is always poorer than that of the sea.

Laterite or red earth – red clay-like products of rock disintegration in humid subtropical regions. Contain iron and aluminium oxides. Externally resemble brick and are used in building, hence, the name from the Latin *later*—brick.

Lava - fiery liquid mass (magma) pouring out of volcanic craters or fissures on to the earth's surface. On hardening forms various volcanic rocks. The latter are deposited in the form of streams (on the slopes of volcanoes) or as crusts (when pouring out of fissures) sometimes covering vast areas.

Lavoisier Antoine (1743-1794)—great French chemist. For his work of compiling the mineralogical atlas of France was elected member of the French Academy of Science.

Lead glance. See *galena.*

Leucite—white or greyish mineral of the silicate group containing aluminium and potassium. Frequently forms sphere-like polyhedrons with twenty-four sides. Encountered as a constituent of intrusive rocks. Attempts are now being made to extract potassium and metallic aluminium from leucite.

Liebig, Justus von (1803-1873)—one of the most prominent chemists of the 19th century. Founder of agronomic chemistry and soil science. Made very important contributions to organic chemistry.

Limespar. See *calcite.*

Limestone—sedimentary rock of white, grey and other colours composed of calcium carbonate ($CaCO_3$); frequently an accumulation of the remains of skeletons and shells. Very abundant in the earth's crust; forms enormous layers. Used in building, cement, chemical and metallurgical industries, in agronomy, and in other branches of the national economy.

Limonite—colloid precipitate of different hydrates of ferric oxides of variable composition. Used as an iron ore. See *iron ore.*

Lithosphere. See *earth's crust.*

Lucretius Carus (99-55 B.C.)—brilliant Roman poet and philosopher. In his poem *On the Nature of Things* he set forth the philosophy of atomistic materialism.

Magma (Greek to dough)—fiery liquid molten mass under the hard crust of the earth. In chemical composition it is a complex molten silicate. Owing to changes in temperature, pressure and other factors magma divides into separate sections; these sections differ in composition; in hardening each of them produces a special rock.

Magmatic or *igneous rocks*—rocks formed from molten magma as the latter cooled and hardened. Divided into intrusive or Plutonic rocks, i.e., hardened in the interior of the earth (granite, peridotite, gabbro, etc.) and *extrusive* rocks, i.e., formed from the magma which poured out to the earth's surface, as during volcanic eruptions (andesite, basalt, liparite, etc.).

Magnesite—white or slightly coloured mineral; magnesium carbonate. Excellent refractory material for metallurgical furnaces, etc.

Magnetite or loadstone—black, opaque mineral consisting of ferric and ferrous oxides; highly magnetic, sometimes forms whole mountains (Magnitnaya and Vysokaya mountains in the Urals). Most important iron ore. See *iron ores.*

Manganese ores are various manganese oxides accumulated amid sedimentary rocks.

Most important manganese-ore minerals are psilomelane, pyrolusite and manganite.

Marble—general name of fine- or medium-crystal granular limestones and dolomites capable of being polished.

Marbles are noted for the diversity of their colours and patterns. Valuable and important building, technical, facing and decorative material. Snow-white and pink marbles are used for sculpture.

Marble onyx—veined deposits of variously coloured calcite. Used as beautiful decorative stone.

Marl—sedimentary rock consisting of clay and limestone mixed in various proportions (argillaceous and calcareous marl).

Marl containing 75 to 80 per cent calcium carbonate and 20 to 25 per cent clay is fit for production of Portland cement without any additions (cement marl or natural cement).

Mass-spectrograph—instrument by means of which it is possible to estimate the number of isotopes in different chemical elements.

Mendelevite—rare black mineral containing niobium and tantalum.

Mercury fulminate—$Hg(ONC)_2$. White or grey poisonous crystalline substance. Explodes readily on being struck, rubbed or heated as well as under the action of certain concentrated acids. Dangerous in use. Used as an explosive.

Metamorphic rocks—rocks of magmatic or sedimentary origin, their mineralogical and chemical composition and structure changed (metamorphosed) after their formation; divided into rocks of Plutonic metamorphism (crystalline shales, micaceous shales, gneisses, etc.), contact metamorphism (corniferous rocks, tourmaline shales, etc.) and partly remelted rocks.

Metamorphism. See *metamorphic rocks*.

Meteor—light phenomenon in the form of a *shooting star* caused by the invasion of a small hard granule weighing a fraction of a gram from interplanetary space into the atmosphere of the earth.

Meteoric body—solid iron or stony mass weighing from a fraction of a gram to many thousands of tons and moving around the sun in interplanetary space as an independent celestial body. In invading the atmosphere of the earth the meteoric body produces a meteor or bolide and sometimes ends by falling on the earth.

Meteorite—iron or stony mass falling on the earth; remnant of a meteoric body which has not fully disintegrated in the earth's atmosphere.

Meteoritics—special branch of science studying meteorites and the conditions under which they fall on the earth.

Mica—group of chemically complex minerals: alumosilicates of alkalis, magnesium and iron. It is a characteristic ability of mica to split into very thin sheets. Chief micas: white mica or *muscovite*—transparent, light and potassic; black or *biotite*—from translucent to opaque, rich in iron and magnesium. Encountered in crystals, sometimes of very large size. Valuable electric-insulation material.

Micaceous shale—schistous rock consisting mainly of mica and quartz with a small amount of feldspar.

Micron—0.001 millimetre.

Migration of elements—shift and redistribution of chemical elements in the earth's crust as a result of which an element is dispersed in some parts and concentrated in others.

Mineral coal—product of large accumulations of various organic (mainly vegetable) remains gradually changed in the course of geological periods. Encountered in layers interspersed with clays, sandstones and other rocks. Layers range from a fraction of a centimetre to several metres thick. Varieties: *anthracite*, *bituminous coal* and *brown coal*.

Mineral oil, *petroleum* or *liquid bitumens*—brown, dark-green or black, sometimes almost colourless liquid. Easily recognized by odour resembling kerosene. Main constituents of petroleum are carbon and hydrogen which form compounds—hydrocarbons—of extraordinarily diverse composition. Mineral oil occurs in layers and pockets and saturates loose or porous sedimentary rocks. It plays an uncommonly important part in various branches of the national economy and is used chiefly as fuel. Refining produces various valuable products – benzine, kerosene, gasoline, lubricants, asphalt, explosives, etc., etc.

Mineral spring – spring with large amounts of inorganic substances dissolved in its waters.

Molecule – minutest particle of substance which cannot be further divided without destruction of its physical and chemical identity. A molecule consists of atoms numbering from one (noble gases) to thousands (proteins).

Molybdenite – lead-grey mineral with metallic lustre. Chemically molybdenum disulphide (MoS_2). Chief molybdenum ore.

Monomineral – consisting of some one mineral.

Morion – almost black rock crystal; its fine fragments, however, appear brown. When carefully heated (baked in bread) becomes light, turning yellow; jewellers take advantage of this property. Further heating may deprive it of all colour. Composition of the colour and its origin are still unknown. See *quartz*.

Mosaics – artistic pattern made of particoloured pieces of stone, glass, wood, bone and other materials closely adhering to each other.

Mountain sickness (altitude sickness) – morbid state as a result of climbing to high altitudes, due to the action of low atmospheric pressure on man.

Murmanite – rare violet-coloured mineral; titanosilicate of sodium from the pegmatites of nepheline syenites.

Muscovite. See *mica*.

Narzan – mineral spring in the city of Kislovodsk. The salts dissolved in its water and the large amount of free carbonic acid give it valuable medicinal properties.

Nephelite, *nepheline* or *eleolite* – greyish-white or greenish mineral with glassy or oily lustre; alumosilicate chemically rich in alkalis.

Nephelite can be used as an aluminium ore in the chemical industry (production of soda, alums, etc.), in the abrasive, porcelain, glass and leather (it replaces tanning materials) industries, in the manufacture of waterproof fabrics, in impregnating wood, as a fertilizer, etc.

Nephelitic syenite – rock erupted from the interior of the earth and containing nephelite, feldspar, pyroxene and amphibole, but never any quartz. Occurs relatively rarely; largest concentration is found on Kola Peninsula.

Nephrite – milky-white, grey, apple-green, sometimes dark, almost black-green mineral. Lime-, magnesium- and iron-containing amphibole. Opaque, but somewhat translucent in thin sheets. Takes polish well. Very valuable, strong and viscous material; consists of microscopically interlaced fibres. Used as building and partly as technical stone.

Neptune – 1. god of water, rivers, streams and rain water in the mythology of ancient Rome. With the development of sea-trade Neptune became the god of the sea and the patron of seafarers; 2. the eighth planet in the solar system; discovered in 1846.

Neptunism – theory of the origin of all rocks (including igneous rocks) from aqueous sediments, very popular with geologists at the end of the 18th and the beginning of the 19th centuries.

Nero (37-68 A. D.) – Roman emperor.

Neutron – elementary particle carrying no electric charge; its weight equals that of the proton. The atomic weight of a chemical element corresponds to the sum of the protons and neutrons in the atom. The neutrons and protons together constitute the nucleus of the atom.

Nontronite—rare apple-green mineral of earthy appearance consisting essentially of hydrous iron silicate; product of weathering of primary silicate.

Ochre—yellow earthy products of oxidation of heavy metals (for instance, vanadic, tungsten, ferric, chromic, lead and other ochres). In the paint trade—dyes of iron hydrates with different water content and of different shades, from earthy-yellow to red.

Octane number—conventional measure of resistance to explosion of liquid fuel. Octane number of iso-octane is 100; that of the very highly detonating heptane is 0. Most types of fuel arrange themselves between iso-octane and heptane.

Olivine or *peridot*—yellow-green, olive-coloured or yellow-brown translucent mineral with glassy glance. Silicate of iron and magnesium.

The transparent golden-green crystals are known as *chrysolite* and are faceted.

Olivinic rocks—igneous rocks from the interior of the earth with the mineral olivine as their chief constituent.

Onyx—variety of agate; consists of layers of different colours, white and black, white and red, etc. The layers are flat and the bands straight; used for making cameos, etc.

Opal—mineral of amorphic (non-crystalline, glass-like) structure; silica with variable water content. Noted for great variety of appearance. Chief varieties—transparent, iridescent and evenly-coloured (noble opal, hyalite, hydrophane, fire opal, etc.), ordinary opals—non-iridescent and not quite transparent (milky, waxy, etc.) and semi-opals—slightly translucent or opaque containing mechanical admixtures (agate, jasper, chalcedonic opals, etc.). Abundant in nature; precipitated in hot and cold waters. Large amounts of opaline substance accumulate on sea floors as a result of vital activity of marine animals and plants (radiolarians, sponges, diatomaceae, etc.).

Ore—mineral or rock containing sufficient useful material to make its processing profitable.

Ore deposits—natural accumulations of ore in the earth's crust which by their beds, extent and percentage of metal content render their exploitation profitable.

Orpiment—arsenic sulphide, yellow mineral usually encountered in leafy and columnar masses.

Orthoclase. See *feldspar*.

Osmic iridium—rare platinum mineral; natural alloy of osmium and iridium.

Outcrop—place where rocks, veins and mineral deposits actually come out to the surface of the earth. Outcrops may be natural and artificial (clearings).

Paleozoic era—ancient era in the history of the earth or era of ancient life. Subdivided into five periods: *Cambrian*, *Silurian*, *Devonian*, *Carboniferous* and *Permian*. Minerals formed on the territory of the U.S.S.R. during the Paleozoic era are very abundant.

Pegmatite—1) vein rocks of various composition formed from residual part of magma saturated with volatile and fusible elements. Pegmatite formations may be connected with various rocks, but *granite pegmatites* are particularly well known. They are noted for very large segregations of feldspar, quartz, dark and white mica and not infrequently for accumulations of precious stones and rare minerals; 2) regular growth of quartz through orthoclase with the formation of structures resembling ancient characters.

Peridotite—dark-grey or black crystalline igneous rock consisting of olivine and pyroxene. Rich in iron and magnesium.

Permian system—layers formed during final period of Paleozoic era: follows Carboniferous period. Name stems from Perm Region where this system is most fully developed and where it was first described.

Permian Sea—sea of the Permian system.

Petrified tree—pseudomorphosis of chalcedony, quartz and opal in a tree.

Petrography—division of geology studying the composition and structure of rocks.

Phenacite—bright wine-yellow, sometimes pale pink-red, transparent to semi-transparent mineral; beryllium silicate.

Phosphates—compounds of phosphorus and various metals. In nature most frequently encountered in combination with calcium and fluorine: apatite, phosphorite, etc.

Phosphorite—variety of the mineral *apatite* of a sedimentary-organogenic origin. Appears as crock- or spherically-shaped concretion with radial structure. Valuable mineral fertilizer if it does not contain much clay and limestone.

Plagioclase. See *feldspar*.

Pliny the Elder (24-79 A.D.)—Roman scientist.

Died during the eruption of Vesuvius. His 36-volume *Natural History*, a sort of encyclopaedia, has come down to our days. In addition to books on biology, botany and medicine it also includes books on cosmography, mineralogy and even the history of art.

Pluto—1) god of the underworld in the mythology of ancient Greece; 2) ninth planet in the solar system; discovered in 1930.

Plutonism—theory that all rocks resulted from the action of underground heat, popular at the end of the 18th century.

Polarizing microscope—microscope adapted to studies of crystalline substances. Used mainly for studying rocks and minerals.

Polaroid—film or plate made of special crystals polarizing natural light.

Polymetallic ore—ore containing several metals, most frequently copper, zinc, lead and silver.

Porphyries—general name of all rocks with large crystals and large grains of minerals (feldspar, quartz) immersed in the main mass which consists of smaller grains.

Proton—elementary particle of substance carrying a positive electric charge. Protons together with neutrons form the nucleus of the atom. The number of protons in the nucleus equals that of the negatively charged electrons and, consequently, the atomic number of the chemical element.

Protuberances or *prominences*—projections on the surface of the sun consisting of heated gases, mainly, calcium and hydrogen. Easily observed during full solar eclipse in the form of fire fountains and eruptions near the edge of the solar disk. Outside eclipses they can be observed only by means of a spectroscope.

Pseudomorphosis—mineral formations of crystalline structure or form atypical of the given mineral. These minerals assume the external form of other minerals, fossillized trees and shells.

Pyrite—iron sulphide: gold-coloured mineral consisting of 46.7 per cent iron and 53.3 per cent sulphur. Very abundant mineral used mainly for the manufacture of sulphuric acid, green vitriol, alum and sulphur.

Pyrites coloured sulphide compounds of copper and iron (also of nickel and cobalt) with metallic lustre. The term came into science from miners who distinguished pyrites from *glances*, i.e., sulphide compounds of the same metals, but of grey and white colours. Examples copper pyrite and copper glance (chalcocite).

Pyroxenes chemically-complex silicates rich in iron, calcium and magnesium: colours grey, yellowish and green up to black. Glassy lustre. Pyroxene has many varieties (enstatite, bronzite, hypersthene, diopside etc.). *Augite* is the usual representative of this group of minerals.

Quartz hard, colourless, white or variously-coloured mineral (SiO_2). Important constituent of many rocks; one of the most abundant minerals in the earth's crust. Occurs in excellently formed crystals as well as in granular and continuous masses. Varieties: transparent quartzes *rock crystal*, *amethyst*, smoky quartz or smoky topaz, citrine; semi-transparent *morion*, milky, grey, etc.; opaque ordinary white, ferruginous, etc. Widely used in the manufacture of physical and optical instruments, in precision mechanics, in radio-engineering, in the glass and ceramics industry, etc.: valuable as a precious and industrial stone.

Radioactivity physical phenomenon whose essence consists in the fact that the atoms of some chemical elements, found mainly at the end of the periodic system, are capable of spontaneous disintegration. As a result of such radioactive disintegration atoms of one element are transformed into those of another.

Radiolarians—microscopically small unicellular organisms belonging to the protozoa. Remarkable for the uncommon variety of their skeletons consisting chiefly of silica.

Rapa brine: water saturated with salts dissolved in it in amounts exceeding those in sea-water: formed in individual closed water reservoirs subject to constant intense evaporation.

Ratovkite. See *fluorite*.

Rock crystal transparent variety of quartz. Occurs in the form of beautiful hexahedral crystals. Used in radio-engineering. See *quartz*.

Rocks natural accumulations of minerals united by a common process of formation and possessing more or less constant composition and structure. Divided into magmatic, sedimentary and metamorphic, depending on origin.

Rock salt. See *Halite*.

Roentgen, Wilhelm Konrad (1845-1923) well-known German physicist. His name won particular fame after his dicovery in 1895 of a special form of radiant energy, the so-called X-rays.

Ruby red variety of corundum used in jewellery, for bearings in watches, meters, etc. Also produced artificially. See *corundum*.

Rutherford, Ernest (1871-1937)–most prominent English experimental physicist who studied the structure of atoms and radioactive processes.

Rutile mineral titanium dioxide (TiO_2): forms reddish-brown crystals. Sometimes encountered grown into quartz in the form of fine fibres, so-called "Venus' hair."

Saline soil saturated with salts to the extent that their crusts or crystals colour it white.

Saltpetre—potassium or sodium nitrate. Occurs in desert regions in thin white crusts on the earth's surface, on rocks, etc. Used as fertilizer and for production of explosives.

Samarskite rare, velvety-black mineral of the niobate and tantalate group.

Sand disintegrated, loose rock formation consisting of rounded or angular grains of separate minerals (quartz, feldspar, etc.) ranging from 2 to 0.02 mm. in size.

Origin product of disintegration, transport and deposit of formerly existing rocks.

Sands are worked for various purposes. Depending on their technical uses the following sorts are distinguished: building, glass, moulding, grinding, filtering sands, etc.

Sapphire. See *corundum.*

Sarder —ancient name (*sard*) of red chalcedony ranging from light to deep shades, as well as from brown-red to brown.

Scale – crust formed on the surface of a molten metal (iron, copper) when air has access to it while it is being processed. The composition of the scale is inconstant and depends on the temperature and the excess of air during its formation.

Scheele, Karl Wilhelm (1742-1786) – outstanding Swedish chemist. Discovered oxygen, chlorine and manganese.

Scheelite opaque greyish-yellow mineral with oily lustre, calcium tungstate ($CaWO_4$). Under the action of ultraviolet rays shows beautiful greenish-blue colour. Mined for production of tungsten, one of the most important elements in metallurgy.

Secondary minerals minerals originated in deposits near the earth's surface as a result of the decomposition of primary minerals under the action of subsoil waters and the oxygen of the air.

Sedimentary rocks stratified rocks formed as a result of precipitation of mineral substances chiefly from water under the action of gravity, for example, limestones, sandstones, etc.

Seismograph or *seismometer* instrument for registering and measuring the waves (shocks) produced in the earth and in engineering structures by earthquakes, explosions, transport, factory machinery, etc.

Seismology science about earthquakes.

Serpentine dense green rock of secondary origin consisting of serpentinite, magnetite, chromite, etc.; often shows green, black, grey, white, red and yellow spots which make it look like snake skin.

Serpentinite hydrous magnesium silicate containing small amounts of iron, chromium and nickel; abundant mineral ranging in colour from onion-green to reddish-green. Used as ornamental stone.

Shales rocks which independent of their origin are characterized by a fine-layer structure and well-pronounced slatiness, i.e., ability to divide into more or less thin, flat and parallel layers or sheets; may stem from sedimentary and from magmatic rocks by means of metamorphism.

Shors saline formed in place of a dried-out lake with clearly pronounced lakeside line.

Silicates large group of minerals representing substances containing silicon and a number of other elements (natural salts of various silicic acids). In the earth's crust silicates comprise the largest group of minerals, including feldspars, micas, horn-blendes, pyroxenes, kaolin minerals, etc.

Silt sediment on the floor of water reservoirs consisting mainly of minutest clayey particles less than 0.01 mm. in size. Soft ground with a low viscosity and rich in water is usually called silt.

Smaragd old name of emerald.

Soffioni volcanic gas streams containing hydrogen sulphide and carbon dioxide, as well as a small amount of ammonia and methane. The best-known soffioni are found in Toscania (Italy). They contain boric acid which is extracted for industrial purposes. The steam of the soffioni is used for heating.

Soil science — science about the origin and development of the soil, the process of development of its fertility and the methods of influencing the soil for crop improvement.

Soils — surface formations connected with the weathering of rocks and remade by water, air and various processes in the vital activity of plants and animals.

Spectral analysis — highly sensitive method of determining chemical composition of complex substances by studying their spectra.

Spectroscope — instrument for studying optical spectra.

Sphalerite or *zinc-blende* — yellow, brown-red, green and black mineral with adamantine lustre. Compound of zinc and sulphur $(Zn, Fe)S$.

Mined for production of zinc. Sphalerite stems from the Greek word *sphaleros* — deceptive.

Stalagmites — formations on the floors of underground caves or galleries formed by drops of water saturated with carbonates falling from the ceiling. Gradually grow from the floor of the cave upward.

Stalactites — masses of calcite and other cylinder-shaped minerals (resembling icicles) hanging down from the ceilings and tops of walls in lime rock of underground caves and galleries.

Step-bearing — support made of a very hard mineral, mainly ruby (natural and synthetic). Used in precision mechanisms. Supports rapidly-revolving parts. Rubies in watches serve as an example.

Stibnite. See *antimonite*.

Stope — part of a mine working where minerals are being extracted.

Strabon (63 B.C.-20 A.D.) — famous Greek philosopher and historian. Travelled extensively through Asia Minor, Syria, Egypt, Italy and Greece. His work *Geography* in 17 volumes has nearly fully come down to our days; the work has been translated into all languages, including Russian.

Sublimation — transformation of substance from crystalline state directly (i.e., without melting) into vapour.

Suess, Eduard (1831-1914) — Austrian geologist. His basic scientific work *Face of the Earth* influenced the development of many branches of geology.

Superphosphate — mineral fertilizer; mixture mainly of calcium sulphate and calcium phosphate. *Superphosphate* is the most widespread fertilizer.

Supersonic waves — mechanical oscillations with a frequency above the upper limit of auditory perception.

Syenite — light-coloured igneous crystalline rock consisting mainly of feldspars and horn-blende.

Differs from granite by absence of quartz. Named after the city of Syene in Egypt.

Talc — magnesium silicate, one of the softest minerals, coloured silvery-white, greenish and yellowish; has oily lustre and is shot with mother of pearl; oily to the touch.

Used in the form of powder for hygienic purposes and as a filler in the rubber, paper, paint and other branches of industry; its dense variety is called *steatite* or *soapstone* and is used in the form of slabs as fire- and acid-proof material and as an electric insulator.

Tectites — small glassy bodies found in many parts of the world. Their origin is still problematic. Some scientists believe them to be meteorites.

Tectonics — branch of geology studying rock deposits and their various irregularities.

Test pit — shallow, vertical shaft-like excavation sunk for prospecting for mineral deposits.

Tiger's eye yellow-brown and brown-black quartz shot with gold owing to inclusions of horn-blende fibres.

Timiryazev, Klementy (1843-1920) great Russian scientist and revolutionary, prominent botanist and physiologist, ardent propagandist of Darwin's evolutionary theory.

Tinstone. See *cassiterite*.

Toluene—chemical compound obtained from coal tar and coke-furnace gases. Basic raw material for production of saccharine; used in manufacture of dyes. Nitrating of toluene produces trotyl, one of the most important explosives.

Topaz transparent, translucent and opaque, colourless, wine-yellow, greenish, blue and pink mineral with glassy lustre. Chemically aluminium fluosilicate. Its transparent beautifully formed crystals are used as precious stones.

Tourmaline mineral of very complex and variable composition alum-borosilicate of calcium, iron and magnesium. Colours vary extraordinarily. Has several varieties. Used as precious stone and as thermo- and piezoelectrical raw material.

Tsiolkovsky, Konstantin (1857-1937) —outstanding Russian scientist and self-taught inventor; devoted all his life to scientific work in the field of rocket-flying.

Turquoise—beautiful blue and bluish-green opaque mineral with a dull lustre; phosphate of copper and aluminium. Used for decorative purposes.

Ultrabasic rocks rocks especially rich in such metals (bases) as magnesium, calcium and ferrous oxide; contain 45 per cent silicon dioxide. All noted for dark (green or black) colours, are heavy and formed from melts in the deepest interior of the earth's crust.

Ultra-short waves—electromagnetic oscillations with a wave-length of less than 10 metres.

Ultraviolet rays general term for electromagnetic waves with wavelengths of 40,000 Å to 100 Å.

Uvarovite chrome garnet of emerald-green colour.

Vacuum space devoid of matter in a closed vessel.

Vauquelin, Louis Nicolas (1763-1829) French chemist. Discovered chromium in Siberian red-lead ore in 1797. The same year found the oxide of a formerly unknown metal, beryllium, in the mineral beryl. Made extensive studies of substance of plant and animal origin.

Vein fissure in rocks filled with some mineral crystallized from the magma or from hot or cold solutions.

Venus' hair rock crystal, smoky quartz or amethyst including rutile and other fibrous minerals.

Vernadskite very rare mineral belonging to the group of basic hydrous sulphates of copper. Encountered in the crater of Vesuvius.

Volcanic (or real) *tuff* rock of pressed volcanic ash. Colour ranges from greyish and delicate violet to black.

Weathering destruction of rocks and minerals by the physical and chemical action of the air and water.

Wolframite brownish-black mineral whose composition includes tungsten, iron and manganese. Contains up to 50 per cent tungsten and yields 95 per cent of its world output. Used in the manufacture of steel and paints.

X-rays or *Roentgen rays* short-wave electromagnetic emanations discovered by W. K. Roentgen in 1895. Have extraordinarily extensive application in science and engineering. The structure of atoms and molecules is studied by means of X-rays. Used in analyzing substance for the purpose of discovering particular elements in it. Also widely used in medicine.

Zinc-blende. See *sphalerite*.

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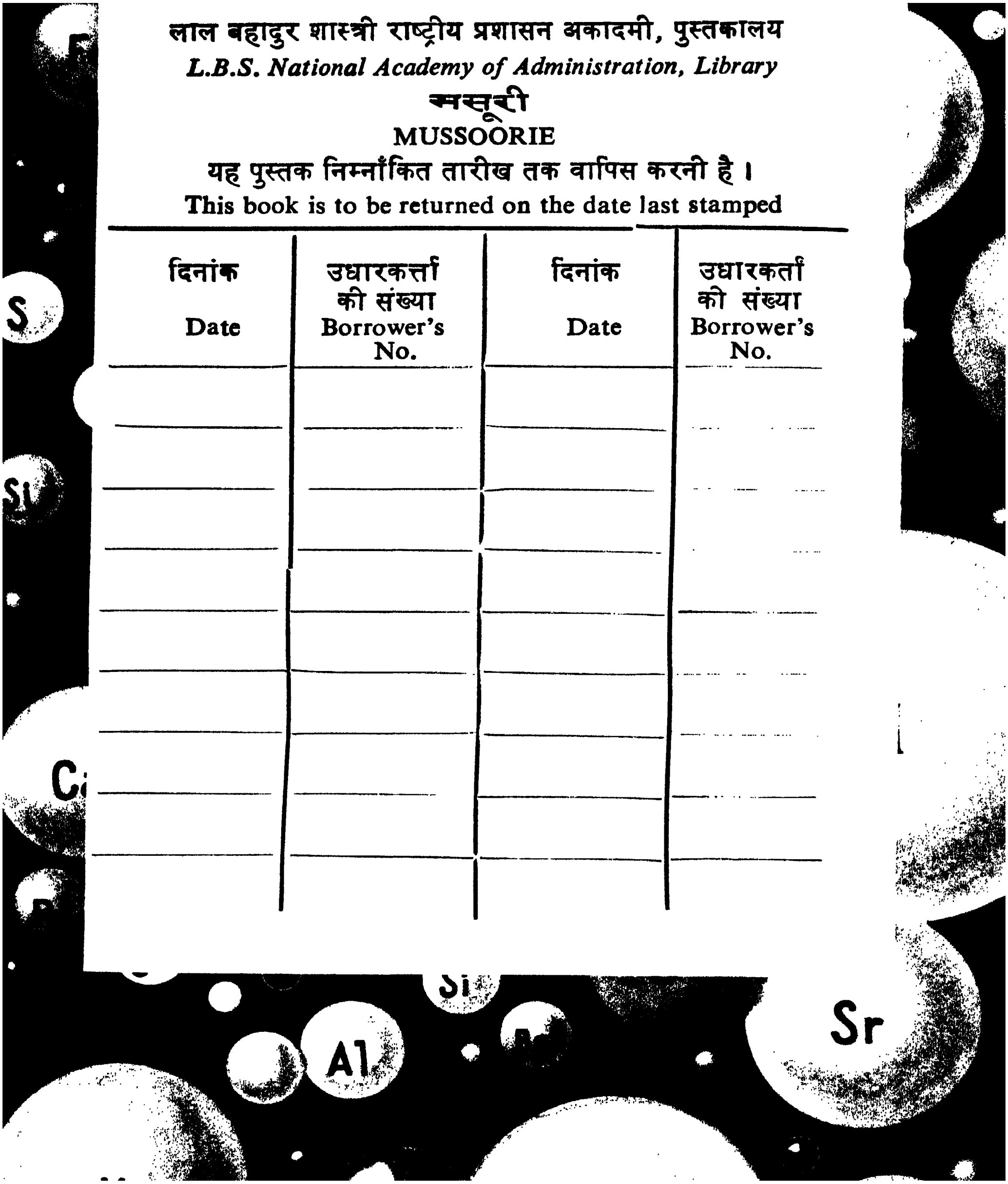

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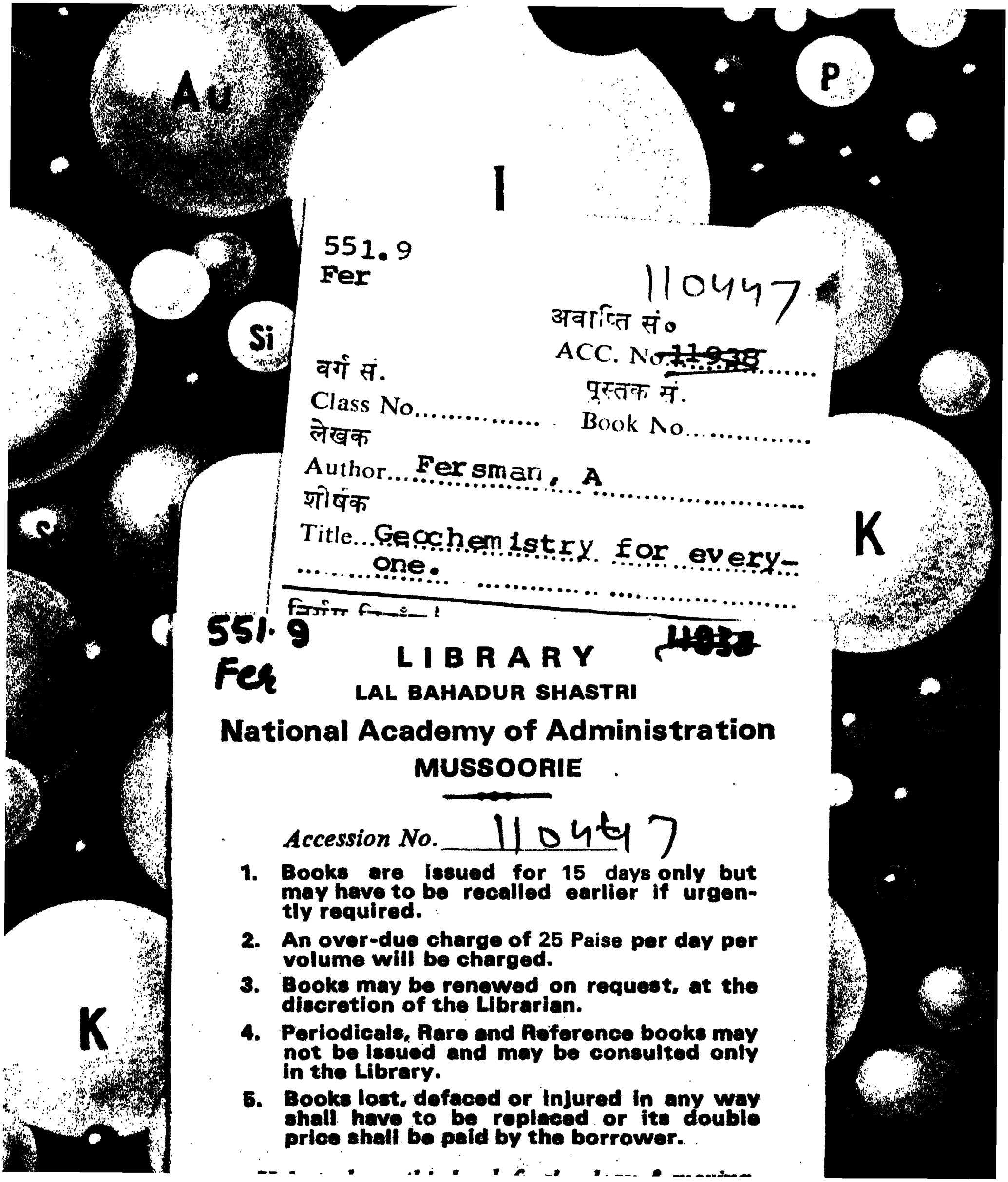

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